UDOT Report No. UT-04.xx

EVALUATION OF FOUR RECENT TRAFFIC AND SAFETY INITIATIVES: VOLUME 1. DEVELOPING A GUIDE FOR EVALUATING THE NEED FOR RAISED MEDIANS

DRAFT FINAL REPORT

Submitted To:
The Utah Department of Transportation
Research and Development Division

Submitted By:
Brigham Young University
Department of Civil and Environmental Engineering

August 2004

UDOT RESEARCH & DEVELOPMENT REPORT ABSTRACT

1. Report No. UT – 04.xx	**2. Government Accession No.**	**3. Recipients Catalog No.**
4. Title and Subtitle EVALUATION OF FOUR RECENT TRAFFIC AND SAFETY INITIATIVES: VOLUME 1, DEVELOPING A GUIDE FOR EVALUATING THE NEED FOR RAISED MEDIANS	**5. Report Date** August 2004 **6. Performing Organization Code**	
7. Author(s) Mitsuru Saito, Ph.D., P.E. David D. Cox, EIT	**8. Performing Organization Report No.**	
9. Performing Organization Name and Address Brigham Young University, Civil & Environmental Eng. Dept. , Provo, UT 84602	**10. Work Unit No.** **11. Contract No.**	
12. Sponsoring Agency Name and Address Utah Department of Transportation 4501 South 2700 West Salt Lake City, UT 84119-5998	**13. Type of Report and Period Covered** Final Report, May 2003 – July 2004 **14. Sponsoring Agency Code**	

15. Supplementary Notes
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16. Abstract

Raised medians are a safety measure often used on highways to improve safety, maintain good traffic flow, and beautify the area. In this study, an extensive literature review was conducted to determine the advantages and disadvantages of raised medians. Raised medians were also compared to other median alternatives, such as two-way left-turn lanes (TWLTL) and undivided highways. Raised medians were found to provide better safety benefits than the other median types. A TWLTL tends to be a compromise between the raised median and the undivided highway because of the improvement in traffic flow and full property access. A survey was conducted on a principle arterial that recently installed a raised median. It was found that although raised medians may be an inconvenience, they do not keep customers from visiting adjacent businesses. Many also realized the safety benefits of raised medians. A crash analysis was also conducted on four highways in the greater Salt Lake City area. Raised medians were found to reduce severe crashes and right angle collisions at the midblock, while rear-end collisions increased at the midblock. Also, vehicle crashes did appear to increase at the intersection. Right angle collisions at the intersection either decreased or stayed the same, and rear-end collisions either increased or stayed the same. Using the information from the literature review, survey and crash analysis, a guide for determining when to install a raised median was formulated. The guide considers crash history, pedestrians, traffic volume, delays, number of driveways per mile, midblock openings, and number of lanes. The guide was applied to St. George Boulevard in St. George, UT, as an example.

17. Key Words Raised median, TWLTL, Crash analysis, Customer and store manager survey	**18. Distribution Statement** No Restrictions. Available from: Utah Department of Transportation Research Division Box 148410 Salt Lake City, Utah 84114-8410 Brigham Young University Department of Civil and Environmental Eng. 368CB Provo, Utah 84602

19. Security Classification (For this report)	**20. Security Classification (For this page)**	**21. No. of Pages**	**22. Price**
None	None		

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ACKNOWLEDGEMENTS

This research was made possible with funding from the Utah Department of Transportation and Brigham Young University. Special thanks are due for all those at the Utah Department of Transportation (UDOT) and Brigham Young University listed below. Additional thanks to everyone else at UDOT for making this research possible.

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1. INTRODUCTION

The Utah Department of Transportation (UDOT) selected a two-year research study of four recent traffic and safety initiatives in the Utah Transportation Research Advisory Committee (UTRAC) Workshop held at Brigham Young University in March 2002. Four traffic and safety initiatives that were included in the study were:

- Roundabouts
- Raised Medians
- Centerline rumble strips
- School zone policies

This research report presents the findings of a study that evaluated traffic, safety and economic impacts of raised medians, especially those that have been constructed on segments of UDOT's highways. The main focus of the study was to develop a guide for determining whether a raised median would be appropriate for a segment of a state highway under consideration.

1.1 Problem Statement

Recently, some cities in Utah that have state highways running through their central business districts (CBDs) have experienced congestion and have requested UDOT to install raised medians. Generally, raised medians improve through movements, provide refuge for pedestrians, and may or may not affect businesses negatively depending on the types of businesses on the adjacent land. They have been installed for various reasons, for instance, the improvement of traffic safety and traffic flow and the beautification of the area. UDOT currently does not have a guide for determining when to install a raised median; therefore, there is a need to develop such a guide that UDOT engineers can use at the time requests for raised medians on state highways are made by local agencies.

1.2 Objectives and Research Methodology

The objectives of this project are to:

1. Conduct a literature review
2. Compare differences between different median types
3. Conduct case studies of recent raised median installations in the local area
4. Develop a guide for determining when to install raised medians in CBDs using the findings from objectives 1 through 3

In the course of the study, two additional objectives were added, which are to:

- Study crash data of four major arterials that have recently been treated with raised medians in Salt Lake County
- Conduct a survey to evaluate impacts on travel behaviors of customers and consensus on economic impacts by store owners and managers

The methodology of the study included a comprehensive literature review, customer and store manager/owner surveys, case study reviews and crash analysis. From the findings of these tasks a guide for evaluating the need for a raised median was developed.

1.3 Organization of the Report

Chapter 2 consists of the literature review. The review covers the differences between the undivided median, the two-way left-turn lane (TWLTL) and the raised median (divided median). It also discusses eight topics relative to the median types with an emphasis on raised medians. Chapter 3 explains the findings of a customer and manager survey conducted at a principal arterial where UDOT recently installed a raised median. Chapter 4 discusses the results of a crash analysis conducted on four highways where UDOT installed a raised median in the last 10 years. The analysis looked at severity, collision type, and location of crashes. Chapter 5 is the conclusion, and Appendix A contains a guide for evaluating the need for a raised median and a sample evaluation. Appendix B, C, and D contains a copy of the manager survey, customer survey, and manager and customer comments, respectively. Lastly, Appendix E contains the raw crash data.

2. LITERATURE REVIEW

A comprehensive literature review was conducted through journal articles from NCHRP, TRB and ITE publications and other resources available on the Internet. Also, AASHTO and FHWA statements were collected and reviewed. Furthermore, practices of other state departments of transportation (DOTs) were examined regarding raised median guidelines and design. The three main topics that were studied were: operations, safety, and economic impact. Special attention was placed to compare the differences among the three typical median treatments:

- Undivided median
- Two-way left-turn lane (TWLTL)
- Raised median (divided median)

From the literature review, the principal differences and similarities among these three median types were enumerated in terms of requirements for right-of-way, safety, operations (particularly left-turn movements), and economic impact.

This section reports the findings from this literature search. It is comprehensive though not exhaustive insofar as time and resources were permitted and the scope is limited to CBDs. The emphasis of the literature search was on raised medians as the purpose of the study indicated.

The findings from the literature review are presented in the following eight sections:

- Safety
- Operations
- Economics

- Aesthetics
- Cost
- Case Studies in Other States
- Models
- Design Considerations

2.1 Safety

In general previous studies indicate that both the TWLTL and raised median would provide an improvement in safety over undivided median, and conversion from the TWLTL to the raised median would improve safety. For instance, Reish and Lalani (1987) reported that four different agencies found that crash rates reduced with raised medians.

- Georgia DOT found that the crash rate for a 6-lane roadway separated by a raised median was 4.4 crashes per million vehicle miles of travel lower than a similar facility with a TWLTL.
- The city of Arlington, Texas found a 66% reduction in crashes due to use of raised medians on 4-lane roadways.
- The New York State DOT reported crash rates for 6-lane undivided highways were 11.28 crashes per million vehicle miles of travel and 7.43 for divided highways, a difference of 34%.
- In a 1982 study by FHWA, the implementation of raised medians resulted in a reduction of crash rates by 5 to 80%.

Reish and Lalani (1987) stated that raised medians are an improvement over TWLTLs because mid-block crashes on roads with TWLTLs become higher on high volume streets.

Mukerjee, Chatterjee, and Margiotta (1993) compared the findings of various median-related studies. One of the studies conducted by Parsonson (1990) concluded that under all conditions a non-traversable median is safer than a TWLTL. However, when the model of Squires and Parsonson (1989) was compared to the models by Parker (1981) and Harwood (1986), they were conflicting in regard to crash rates. Also reported, were state design engineers did not come to a consensus when choosing between a TWLTL and a raised median.

Nevertheless, there are many findings in the literature that raised medians would be effective in reducing the overall crash rates. In the National Cooperative Highway Research Program (NCHRP) Report 420 (1999), Gluck, Levinson and Stover presented the average annual crashes per mile predicted from several safety models for the three types of median treatments as shown in Figure 1. In this figure accidents per mile are related to Average Daily Traffic (ADT). As shown in Figure 1, the raised median has fewer annual crashes per mile than either the TWLTL or the undivided road.

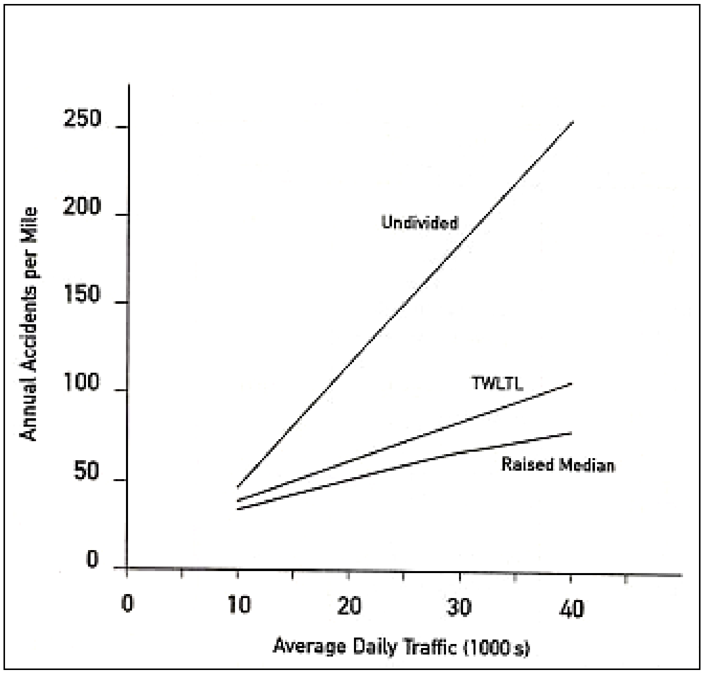

Figure 1: ADT versus annual crashes per mile
(Source: Gluck, Levinson and Stover 1999)

The Center for Transportation Research and Education (CTRE) reports that in addition to having more frequent crashes with higher traffic demand there are more frequent crashes with greater driveway densities, as cars make more frequent left-turns and right-turns (CTRE 2003d). The table below shows the relation between access points per mile and crash rate on undivided, TWLTL, and raised median roads presented by the CTRE.

Table 1: Crash rates by access points per mile

Access Points Per Mile	Undivided Roadway	TWLTL	Raised Median (RM)	Crash Rate Reduction TWLTL vs RM
<20	3.8	3.4	2.9	15%
20-40	7.3	5.9	5.1	14%
40-60	9.4	7.4	6.5	12%
>60	10.6	9.2	8.2	11%

Note: Crash rates per 100 MVM
(Source: Bonneson and McCoy 1997)

Removing left-turning traffic from main-flow through lanes will improve traffic safety, which is accomplished by TWLTLs and by left-turn bays in raised medians. For the TWLTL, however, when traffic volumes become too high or if there are concentrated left-turns, safety may be compromised. Since TWLTLs have some of the benefits of both raised medians and undivided medians, they have been considered a compromise solution by Bonneson and McCoy (1998). One of the concerns for raised medians is that crashes may migrate to the surrounding neighborhoods. There is also concern about TWLTLs being associated with more head-on collisions (Dixon, Hibbard, and Mroczka 1999).

Bonneson and McCoy (1998) reported that raised-curb medians are associated with fewer crashes than the other two types, but if U-turn activity increases, crashes may increase and reduce the safety margin between raised-curb medians and other median types.

As to the effect of the number of driveways on crash occurrence, Azzeh et al. (1975) found that when driveway density was 60 or more per mile, non-traversable medians were safer. In other situations, a TWLTL was safer.

As for pedestrian safety, previous studies show raised medians are advantageous for pedestrians because they provide pedestrian refuge areas in the middle of the highway. Islands, or raised medians, allow pedestrians to cross the road in two smaller segments, which allow them to look in one direction before crossing instead of two. Also, pedestrians wait for a smaller gap to cross with raised medians because they only have to cross half as many lanes (FHWA 2003). Figures 2 and 3 show the difference in pedestrian safety in the crossing maneuvers.

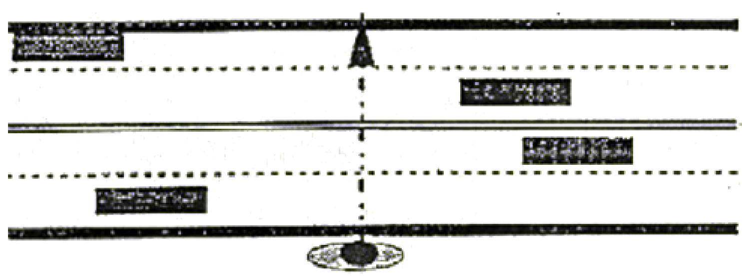

Figure 2: Mid-block pedestrian crossing without raised median
(Source: FHWA 2003)

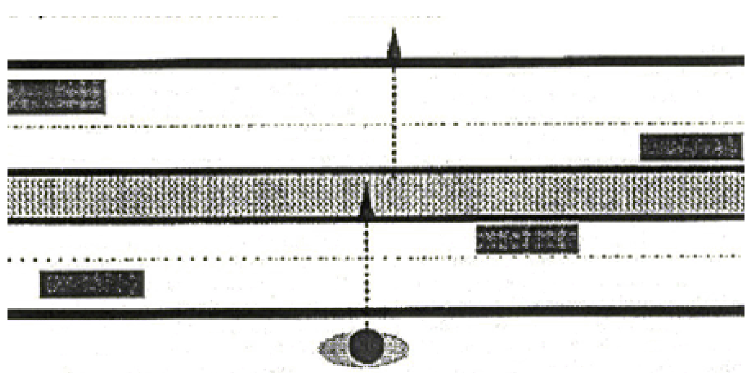

Figure 3: Mid-block pedestrian crossing with raised median
(Source: FHWA 2003)

As shown by Figures 2 and 3 raised medians reduce the number of conflict points that pedestrians encounter, because vehicle maneuvers become more predictable. Raised medians are similar to reducing driveways or putting more distance between driveways, in that safety is improved as left-turns are reduced, making access points safer. With raised medians traffic will enter and exit driveways in one direction. Even if a mid-block opening is provided with a raised median, traffic movements are more predictable than before (CTRE 2003b).

Figure 4: Pedestrians cross road with raised median
(Source: FHWA 2003)

The Florida DOT recommends providing adequate pedestrian safety in high pedestrian zones. It also recommends that medians be considered in existing as well as new school zones, entertainment districts, tourist zones, residential neighborhoods and other high volume pedestrian areas; they should especially be considered when these high pedestrian roadways have four or six lanes of traffic (FDOT 1995).

Table 2 shows pedestrian and crash rates by roadway type for mid-block and intersection locations. As shown in the table pedestrian crash rate is much smaller for divided 4 lane roads than for undivided or TWLTL roads. Also note that the pedestrian crash rate is similar for undivided and TWLTL cross-sections. To experience these benefits, it is recommended that the median be at least 4 feet in width (CTRE 2003b). The CTRE also found that roads with raised medians are “roughly twice as safe for pedestrians” than roads with other median types. This is important for children and the elderly because they have less adequate gap assessment skills – skills needed to assess when to cross the street. Also, people have reduced gap assessment skills at night (FHWA 2003).

Table 2: Mid-block and intersection pedestrian crash rates by roadway type

Roadway Type	Median	Mid-block pedestrian crash rate[a]	Intersection pedestrian crash rate[b]
Undivided 4 lane	None	6.69	2.32
5 lane (TWLTL)	Painted	6.66	2.49
Divided 4 lane	Raised	3.86	0.97

Note: a = per million vehicle miles, b = per million entering vehicles
(Source: CTRE 2003b)

A similar statement was made by ITE (2003) that raised medians have been found to reduce crashes 25-40% and they can be used as a refuge for pedestrians. However, raised medians can be dangerous if struck at high speeds, and their visibility at night is an issue unless they are well lit.

The CTRE (2003b,d) list a few advantages of raised medians over TWLTLs:

- They prevent crashes caused by crossover traffic,
- They reduce headlight glare, and
- They provide pedestrian protection.

It recommends that raised medians be considered when pedestrian safety or serious crashes are a concern; however, TWLTLs may be adequate for serious crashes other than pedestrian accidents. Also, TWLTLs should be avoided on roads with more than 2 lanes in each direction because pedestrian crash rates increase dramatically (CTRE 2003b).

In some studies, however crash rates increased after the installation of raised medians. Dixon, Hibbard, and Mroczka (1999) stated, in their study, three median improvement projects where they installed raised medians the number of right angle crashes and overall crashes increased. However, the crash rates of the locations where raised medians were not installed were still higher, given the rapid growth of the area. Furthermore, they reported that median-related crashes would not migrate to the bounding signalized intersections as long as U-turns would occur at median openings.

Dixon, Hibbard, and Mroczka(1999) also reported that the general public still had concerns for TWLTLs and raised medians at the time their study was conducted. Safety concerns brought up by citizens concerning TWLTLs and raised medians were:

- The TWLTL would be a suicide lane,
- U-turns at intersections or mid-block openings would disrupt traffic flow, and Raised medians would encourage vehicles to travel at higher speeds

Despite these general concerns, Gluck, Levinson, and Stover (1999) report that TWLTLs and raised medians have been found to reduce potential for rear-end crashes near intersections and reduced crashes by 35% in suburban areas and 70 to 85% in rural areas. Consistent reductions were reported in rear-end, sideswipe, head-on and fixed end crashes, and left-turn crashes generally decreased.

2.2 Operations

Traffic operations related to raised medians include access to adjacent businesses, delay, and traffic flow. Raised medians are more often preferred when safety is a concern, but they do have advantages that are important to recognize in terms of traffic operations. Table 3, created by the author of the report) shows the relative levels of access, delay and separation of traffic for raised median, TWLTL and undivided roads. For example, delay caused by left-turning vehicles is not a concern for raised medians when there are left-turn bays either at mid-block locations or at intersections. Also, raised medians are desirable for left turn storage when left-turn volumes are high (Van Winkle 1988). Furthermore, traffic flows better on raised medians because of separation of traffic. However, access to adjacent business is a concern because left-turns are blocked by raised medians at mid-block locations.

Table 3: Relative levels of access, delay and separation of traffic between median types

	raised median	TWLTL	undivided road
access	low	high	high
delay	low	low	high
separation of traffic	high	medium	low

A TWLTL is usually the best alternative in terms of operations because it has the benefits of direct access provided by undivided roads and the benefits of decreased delay for through vehicles provided by raised medians (Gluck, Levinson, and Stover 1999; Dixon, Hibbard, and Mroczka 1999). As to delay, Bonneson and McCoy (1998) reported that raised medians and TWLTLs yield similar delays on arterials.

Other advantages offered by the TWLTL include (ITE 2003):

-

- Maneuverability and flexibility is much greater than the raised median,
- It does not have the penalty associated with hitting an object,
- TWLTLs may not be associated with increased U-turns,
- They provide a storage area for left-turning vehicles, and
- Drivers can take more direct routes when entering and exiting adjacent properties.

Also, TWLTLs are often preferred by fire fighters. Fire fighters have historically opposed raised medians for several reasons. A raised median “forces fire equipment to stop behind traffic at red lights since an apparatus is unable to detour to the other side of the street” (Los Angeles Evening Outlook 1962). In 1967, a report by chief engineer and general manager of the Board of Fire Commissioners, gave three reasons for opposing raised medians (Hill 1967):

- They slow emergency response to a high degree,
- In built-up areas, it is difficult to operate in the vicinity of large and extensive fires, and
- The above factors raise insurance rates to businesses.

U-turns are of another concern when median types are evaluated. A Circulation letter, No. 66-108 of the Division of Highways of the Department of Public Works of California (1966) stated that continuous curbed medians should be avoided when streets are too narrow for U-turns. However, Bonneson and McCoy (1998) found that it might not matter if U-turns are possible. They concluded that U-turn activity would be a negligible issue for raised medians at the mid-block location because drivers either cannot make left-turns or they will be able to use the mid-block opening to arrive at a destination. Also, they prefer to take alternative routes where a right turn can be made instead of a left-turn. Besides, making a U-turn may not be worth one's time. Bonneson and McCoy (1998) studied mid-block performance and found that incremental delay for an alternative route is less than taking a U-turn at a downstream intersection.

Several reports encountered during the literature review cite advantages and disadvantages of raised medians; they are summarized below:

- Control of speed (Stover et al. 1982, CTRE 2003d)
- Decrease in conflicts (Stover et al. 1982, Parker 1983)
- Increase in capacity and safety (Stover et al.1982)
- Enhancement of traffic flow (Stover et al. 1982)
- Regulation of traffic (Stover et al. 1982)
- Clearer indications of travel lanes at intersections (Stover et al. 1982)
- Favor predominant movement (Stover et al. 1982)
- Increase area for traffic control devices (Stover et al. 1982)
- Increase area for pedestrian refuge (Stover et al. 1982)
- Encourage development of alternative access roads (Parker 1983)
- Concentrate left-turns at mid-block opening or intersection (ITE 2003)
- Discourage strip development (CTRE 2003d)
- Control of land uses (CTRE 2003d)

In summary, raised medians maintain speed and traffic flow well because there are less conflicts for drivers to worry about. Traffic movements are regulated well by the physical barriers of raised medians, as they clearly mark travel lanes. Raised medians can be tailored to a certain traffic movement. For example, raised medians can have mid block openings that allow left turns from the road but not from a driveway. Traffic engineers can use the unused surface of the raised median to erect traffic signs, signals and other traffic control devices. The development of alternative access roads around the road with raised medians is an important step, so that drivers can navigate to businesses through the streets around the road with raised medians. Also, strip mall development with unregulated accesses can not only create an aesthetically unappealing streetscape, but also increase conflict points. Raised medians help discourage the development of such streetscape because raised medians force the developers to consider safe circulation of traffic to their stores.

There are obvious disadvantages of raised medians, shown below.

- Undesirable conditions for turning movements (e.g. U-turns) (Parker 1983, ITE 2003, CTRE 2003d)
- Travel increases on local streets other than arterial with raised median (Parker 1983)
- Increase travel time and delay of some left-turning traffic (ITE 2003)
- Limit property access (CTR 2003c,d)
- Concentrate left-turns (CTR 2003d)

In summary, raised medians can be frustrating to some drivers and they may have to travel extra to get to the destination. Second, traffic may increase on local streets nearby and the residents on those streets may complain. Third, as travelers use local streets and travel to intersections to reach their destinations due to limited direct access to properties instead of making direct left-turns on undivided roads or on TWLTL median, travel time and delay may increase for some. Fourth, the concentration of left-turns at mid-block openings and intersections could lead to spill-overs from the left-turn bays that would eventually block vehicles on through lanes.

One benefit of raised medians is clear and for that reason raised medians are preferred to TWLTLs at intersections. When raised medians are installed at intersections, they separate slower left-turning traffic from through traffic and provide a protected space to decelerate and turn, as long as the length of a left turn bay is adequate. In contrast, roads with TWLTLs do not always provide protection for mid-block left-turning vehicles because of potential left-turning vehicles in the opposite direction sharing the same direction. Another important advantage is raised medians do not allow left turns to or from driveways within the functional area of the intersection. This helps relieve congestion and significantly reduces the number of conflicts points near or at intersections. These benefits are highest when the intersection approach volumes are high and traffic safety is low (Raised Medians at Intersections 2003).

2.3 Economics

Frawley and Eisele (2001) found that the impacts of a raised median are less drastic than prior perceptions of business owners. However, they found the construction time period is most detrimental to businesses. To alleviate impacts on businesses during the construction, adequate and visible access must be ensured, construction time reduced, and construction performed in smaller segments. Public meetings can also alleviate some impacts of the construction phase (Frawley and Eisele 2001). Reish and Lalani (1987) reported that in Overland Park, KS, the installation of a raised median caused no known business failure.

Figures 5 and 6 were taken from Frawley and Eisele's study (2001) and present the raised median impacts for businesses. They give the percentage of managers that believed certain items relating to raised medians became better, stayed the same or got worse. The items checked were:

- Traffic congestion
- Traffic safety
- Property access
- Business opportunities
- Customer satisfaction
- Delivery convenience

Figure 5 shows the result of a survey done before median installation, while figure 6 is the post-median installation survey done with those present before, during, and after the installation.

For businesses interviewed before median installation, the majority believed traffic congestion and traffic safety would be better. Also, the majority believed that business opportunities would be the same and property access would be worse. There was no decisive opinion either way concerning customer satisfaction or delivery convenience.

Opinions changed when asked after the median installation. For businesses present before, during and after median installation, the percentage of businesses that believed traffic congestion and traffic safety would be better decreased slightly although it is still very high. Also, the percentage of business that believed property access would be worse decreased approximately 16%. Furthermore, the percentage of those that felt business opportunities would be better increased almost three times, from 15% to 40%.

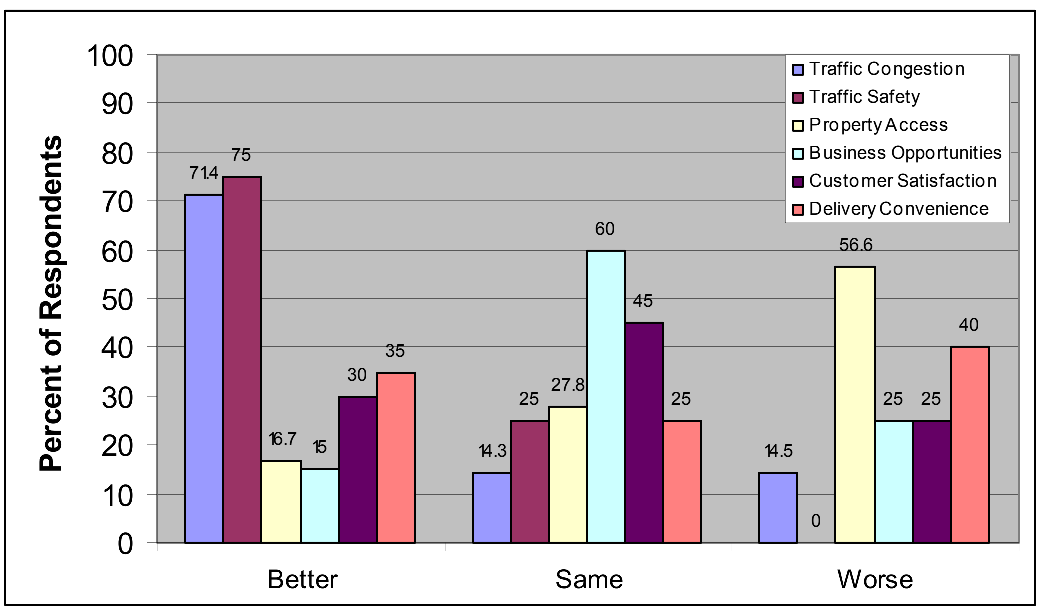

Figure 5: Raised median impacts for businesses interviewed before median installation
(Source: Frawley and Eisele 2001)

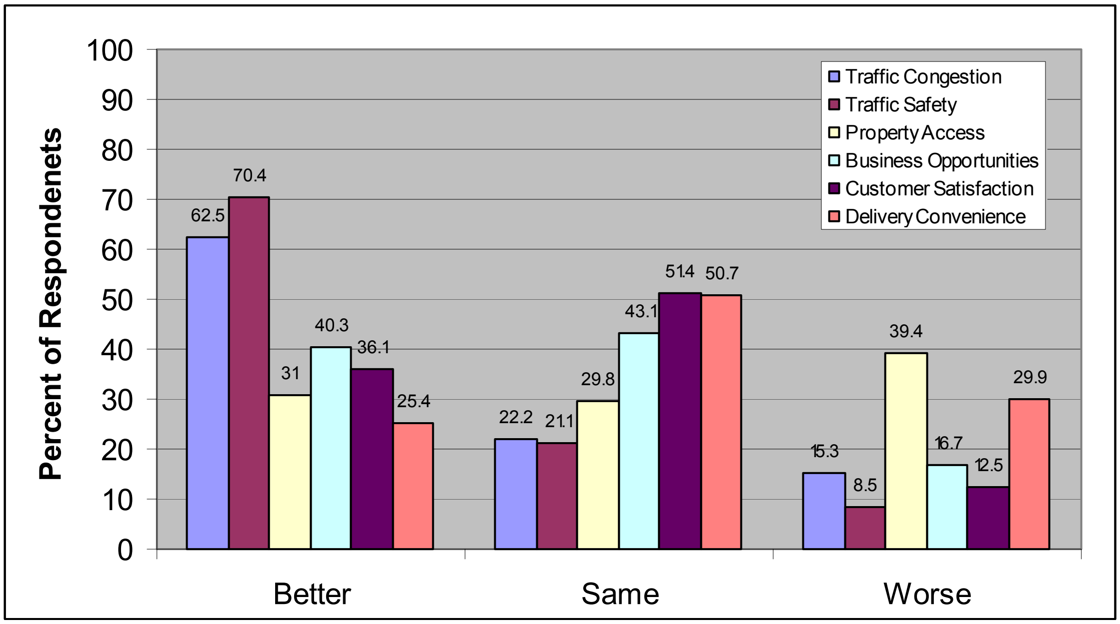

Figure 6: Raised median impacts for businesses present before, during, and after median installation
(Source: Frawley and Eisele 2001)

Another business vitality study was conducted in Iowa on nine access management project locations (CTRE 2003a) Access-managed corridors generally had more rapid growth in retail sales once projects were completed. More business owners reported stability in sales or an increase in sales compared to those who reported a decrease after completion of an access management project. Traffic-dependant businesses, such as convenience stores and fast food restaurants, appeared not to be affected in a different manner than all the other businesses. Short-term losses for businesses were not found to be significant during the project. Over 80% of businesses found access management projects resulted in gains, stayed the same or did not know. Five percent reported losses after the access management project. About 19% of business owners reported customer complaints, and half of those businesses were auto-oriented businesses (i.e. gas stations, convenience stores and fast-food restaurants, etc.). Over 80% of business owners reported no customer complaints. TWLTLs generally receive low levels of business owner complaints and customer complaints, and raised medians received low levels of customer complaints. Furthermore, auto-oriented businesses tend to be the least supportive of raised median projects (CTRE 2003a).

Very similar results were found in a 1996 study in Indiana (CTRE 2003a). The study indicated the average loss of business during construction of a major project is 13%. The biggest temporary losses came from gas stations, grocery stores, consumer electronic stores, hardware stores, and automotive sales and service firms. This study indicated that businesses recovered within 2 years and that 20% of businesses experienced long-term reduction in sales. Business types most likely to experience long-term detrimental impact were gas stations, car washes, and other automotive-related businesses. The majority of businesses reported that the projects benefited them, and the majority supported the projects (CTRE 2003a).

The CTRE (2003a) indicates one advantage and one disadvantage of raised medians in terms of economic impact. The advantage of a raised median is reduced fuel consumption and tailpipe emissions. This is due to the efficiency with which vehicles can travel on a separated roadway. The disadvantage is businesses and land owners may oppose a raised median project because they believe it will have large negative economic impacts. However, raised medians typically do not hurt business vitality. According to the findings, it is most likely that auto-oriented businesses will be the most opposed to raised median projects

2.4 Cost

Construction of the median type and the right of way required is always a concern of the builders. This information is available in Table 4. Costs of changing from one type of median to another may affect the decision of selecting a particular median type, as well. This information is in Table 5.

In Table 4, the cost for a TWLTL and a raised median are similar. However, the cost for an undivided road is quite a bit less. The reason for the discrepancy in cost is the number of lanes required. To construct a four-lane road, an undivided road requires only four lanes, whereas a TWLTL and a raised median require the equivalent of five lanes. The requirement for additional lanes also increases the right-of-way (ROW). Besides the wider roadway, raised medians require curbs and sometimes landscaping in the raised median structure. However, even though undivided roadways are cheaper than raised medians, the cost of a raised median is insignificant with regards to total project cost when it is part of a large construction project (Dixon, Hibbard, and Mroczka 1999).

Table 4: Estimated development costs per mile for different median treatments

Cost Item	Area Type	Built-Up Urban Area			Outlying Urban Area		
	Median	Undivided	TWLTL	Raised[3]	Undivided	TWLTL	Raised[3]
Unit Costs (thousands of dollars per lane-mile)[1,2]							
Construction		745	769	980	901	925	1,136
Right-of-Way		472	472	472	191	191	191
Total		1,217	1,241	1,452	1,092	1,116	1,327
Cost for a Street with Four Through Lanes (thousands of dollars per mile)[1]							
Construction[4]		2,980	3,749	3,960	3,604	4,529	4,740
Right-of-Way		1,888	2,360	2,360	764	955	955
Total		4,868	6,109	6,320	4,368	5,484	5,695

Notes:

1. 1996 dollars using Consumer Price Index
2. Costs from the "Undivided Highways, Pavement Reconstruction" category of Table 4-16 in Thomas 1996.
3. Incremental cost of Raised-curb over TWLTL was based on the average of values reported by Harwood 1989 and Parker 1991 (i.e. 211,000).
4. Construction costs for TWLTLs and raised medians equal 5 times the unit cost for an undivided roadway plus $24,000 and $235,000, respectively.

(Source: Gluck, Levinson and Stover 1999)

Table 5: Ranges in costs for mid-block left-turn treatments (in 1996 dollars)

Reconstruction (or conversion) Combination	Estimated Difference in Construction Costs (Thousands)	Annualized Costs	
		Dollars per mile	Dollars per Quarter-Mile
Undivided to Raised Median	$1,452 (a)	$106,841	$27,000
Undivided to TWLTL	$1,241 (a)	$91,315	$23,000
TWLTL to Raised Median	$980 (b)	$72,110	$18,000

Notes:
a: Difference in construction and ROW costs (Table 52 of Gluck, Levinson, and Stover 1999
b: Cost/mile to build raised median.
Debt service factor (20 yrs at 4%)
(Source: Gluck, Levinson and Stover 1999)

2.5 Aesthetics

Landscaped medians are recommended for improved aesthetics and pedestrian activity (Reish and Lalani 1987, CTRE 2003b, CTRE 2004a). They can enhance the public's support for the project and improve safety in all aspects (CTRE 2004a). Dixon, Hibbard, and Mroczka (1999) report that an unattractive median may be a catalyst for uncontrolled commercialization. For instance, citizens of Atlanta were concerned about the future development of a road in a residential area because an unattractive raised median was installed. This road eventually became a strip of auto-oriented businesses. Such a rampant development of strip malls reduces the aesthetics of the area and decrease the value of the community as residential area. On the other hand, a beautified median can enhance the attractiveness of an area and increase the value of the area. Here are some examples of how a median can be landscaped.

A median can have flowers, shrubs and trees (Figure 7) or just grass (Figure 8). But if it is not landscaped well, it could make the surrounding area look harsh and less pleasant (Figures 9 and 10).

Figure 7: Raised median with trees and flowers
(Source: City of Madera 2004)

Figure 8: Raised median with grass and rocks
(Source: CTRE 2004a)

Figure 9: Raised median without landscaping
(Source: Knoxville 2004)

Figure 10: Median without pleasant landscaping
(Source: CTRE 2004a)

2.6 Learning from Previous Case Studies

Review of several previous case studies revealed different reasons and trends for installing raised medians. This section summarizes four cases encountered during the literature review.

2.6.1 Case Study 1

In the July 1993 edition of the ITE Journal, Mukherjee, Chatterjee, and Margiotta reported the results of an experiment where state design engineers were given hypothetical situations, of which they voted for the best remedy. Three cases were presented in this experiment, which were:

- Rural area expected to become suburban
- Existing suburban commercial area
- Existing suburban residential area

Discussions on the first and third cases are skipped in this report since they do not fit into the scope of this study. In the second case, the existing conditions were:

- 4-lane undivided highway
- 2 miles of strip commercial use
- Numerous rear-end crashes and delay problems
- Current ADT = 25,000; Design ADT = 30,000
- Speed limit = 40 mph
- 5 signalized and 10 unsignalized intersections
- 150 uncontrolled driveways

Based on the second case, design engineers were asked which median treatment they would prefer. Table 6 shows the percentage of design engineers that preferred different median treatments. Almost one half of the participants preferred a TWLTL in this situation, whereas about a quarter preferred the non-traversable (i.e., raised) median. Even though there is a large number of driveways and the ADT is relatively high, that half of the questioned design engineers prefer a TWLTL in a commercial area.

Table 6: Design Engineers choice

Treatments	Percent choosing
Non-traversable median	26%
TWLTL	45%
Traversable median	3%
Other	3%
No response	23%

(Source: Mukherjee, Chatterjee, and Margiotta 1993)

The conditions from the second case “Existing Suburban Commercial Area” were inputted into three different median treatment models, created by Parker (1981), Squires and

Parsonson (1989) and Harwood (1986). Table 7 shows what median the models favored in terms of crash rates and delay. Two out of three models preferred the TWLTL in terms of crash rates, and one out of two preferred the TWLTL in terms of delay.

Table 7: Treatment preferred by models

	Parker	Squires and Parsonson	Harwood
Crash rates	Median	TWLTL	TWLTL
Delay	Median	NA	TWLTL

(Source: Mukherjee, Chatterjee, and Margiotta 1993)

It is likely in this case that a TWLTL was more popular with the design engineers because the road was for commercial use. The non-traversable median was likely popular because of the ADT and for controlled access.

2.6.2 Case Study 2

This case study comes from the August 1987 edition of the ITE Journal (Reish and Lalani 1987). The Public Works staff of Lakewood, CO, looked into the possible ways to widen Wadsworth Boulevard, a major arterial in Cobb County, GA in the greater Atlanta area that has seen significant growth in vehicular volume.

The details of the arterial are as follows:

- 4-lane arterial with TWLTL
- Acceleration and deceleration lanes at high volume driveways
- Afternoon peak-hour volume (PHV) = 4,100 vph
- 20-year projections predict continued growth

This arterial was not adequate to serve the increased traffic volume. Therefore, a survey and a literature search were conducted in order to find the best solution to meet the demand.

Three improvements were recommended:

- Install a raised median throughout the length of the project,
- Provide adequate street widths and signal phasing for U-turns at intersections, and
- Construct a secondary circulation system which will allow drivers to get to adjacent land uses easier.

All three solutions were to be simultaneous.

The above recommendations were based on the following conditions:

- Volume greater than 25,000 vpd, which is the suggested threshold for TWLTLs
- Crash rates indicate a need for the improved safety of raised medians
- U-turns could be accommodated
- Raised medians would improve aesthetics
- Lack of evidence that businesses would fail due to raised median

2.6.3 Case Study 3

A raised median was built at the intersection of US Highway 18 and Pierce Avenue in Mason City, Iowa (CTRE 2003c). During the three years after the completion of the project, the number of crashes decreased by 40%. The project changed the number and configuration of driveways within the functional area of the intersection. The turning traffic at the intersection and commercial driveways was the primary reason for the high crash rate before construction. Left-turn lanes built into the raised median protect left turning vehicles by allowing them to slow down at a low deceleration rate and at the same time to be away from the path of through vehicles. The raised median reduced the conflict points, and an improvement in capacity and safety took place even though volumes increased by 16%.

2.6.4 Case Study 4

Dixon, Hibbard, and Mroczka (1999) reported a case where compromise was made and part of one road received a TWLTL and the rest a raised median. Wade Green Road in Cobb County of the greater Atlanta, Georgia area is characterized by two different land uses. North of Hickory Grove Road the land use is residential and south of Hickory Grove Road, the land use is commercial. Hickory Grove Road runs perpendicular to Wade Green Road. The Cobb County DOT recommended a TWLTL for the length of the project. In general, business owners and residents who lived directly on Wade Green Road favored the TWLTL. This is because a raised median would restrict access to the businesses and homes. Residents who did not live on Wade Green Road represented the majority, and they favored the raised median. The final outcome was a compromise. North of Hickory Grove Road became a raised median, and south of Hickory Grove Road became a TWLTL. After construction, rear-end collisions decreased from 36% to 15%, right-angle collisions increased from 16% to 44%, fixed object collisions decreased 28% to 10%, and sideswipe collisions increased from 10% to 24%. The average annual number of crashes also increased from 31 to 41.

2.7 Models

Bonneson and McCoy (1998) developed an Operations Analysis Model, which outputs capacity, delay, probability of bay overflow and queue length for all traffic movements at each intersection and arterial through movement travel speed. This model studies mid-block performance. The model consists of smaller component models, which include:

- Arterial through vehicle delay due to left-turn bay overflow
- Arterial through vehicle delay due to left-turn or right-turning vehicles
- Arterial through vehicle delay due to high traffic volume

- Delay due to spillback from a downstream intersection
- Effect of signal-induced platoons on un-signalized intersection capacity and delay

Overall, the model is based on Chapters 9 and 10 of the 1997 *Highway Capacity Manual* (TRB 1997). Figure 7 shows results of this model for one scenario, which has four through lanes, 10% left-turns per ¼ mile, and 60 active access points per mile. An "active" access point is defined for this model as having an entering volume of 10 vehicles per hour or more.

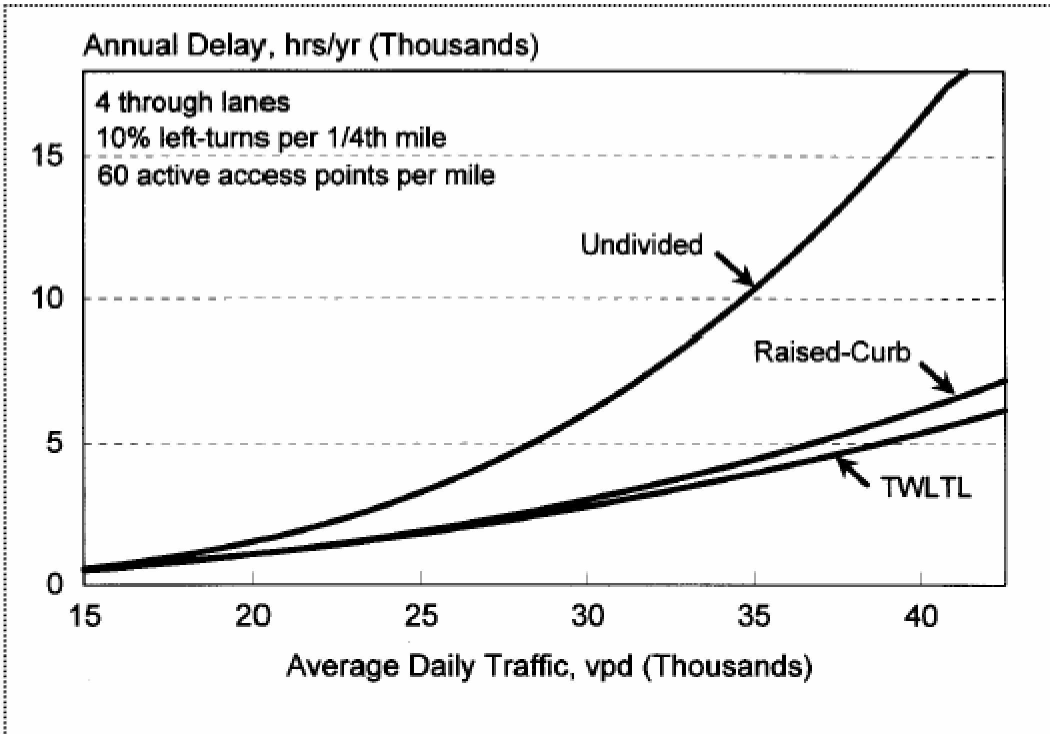

Figure 11: Annual delay versus average daily traffic

(Source: Bonneson and McCoy 1998)

As seen in Figure 11 the undivided cross section has the most delay. Figure 11 also shows that the raised curb median has slightly more delay than the TWLTL. This is probably due to concentrating the left-turns at intersections which may overflow into the through traffic.

Bonneson and McCoy (1998) also calibrated a regression model that predicts expected annual crash frequency based on its length, average daily traffic demand, median treatment, adjacent land use, and total access point density (active and non-active). The model was calibrated using data from Omaha, Nebraska and Phoenix, Arizona. The database includes 189 street segments that experienced 6,391 mid-signal street crashs in a three-year span.

Figure 12 presents the results of the safety model for a quarter-mile segment of an arterial street with 65 access points per mile and no parallel parking.

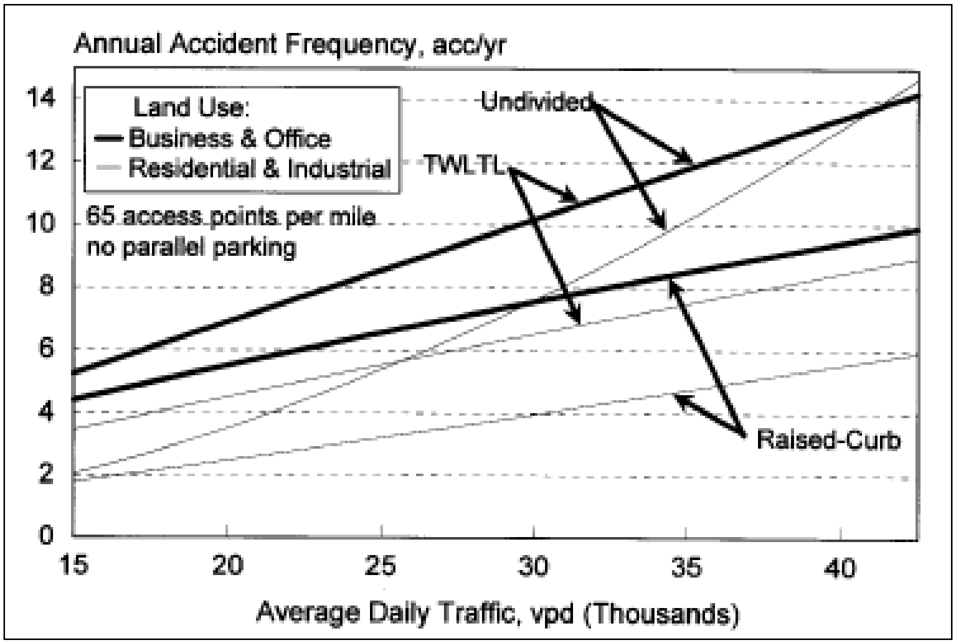

Figure 13: Average daily traffic versus annual crash frequency
(Source: Bonneson and McCoy 1998)

As seen in the figure the annual crash frequency is similar for undivided and TWLTL median treatments. Bonneson and McCoy (1998) explained that this similarity was caused by the restriction on parallel parking that the streets in the database had. The figure also shows that raised curb medians have lower crash frequency for both land uses.

Bonneson and McCoy (1998) used their operations and safety models to determine the benefits of the median types using the construction cost of the different median types as a comparison factor. The results were tabulated for four-lane arterial streets in business and office areas as shown in Figures 13 and 14. The figures suggest when it may be appropriate to convert from one median type to another based on benefit-cost ratio. Bonneson and McCoy (1998) did not tabulate the conversion from a raised-curb median to an undivided road because the cost of conversion outweighed the benefits.

Average Daily Traffic (vpd)	Active Access Point Density[1] (ap/mi)	Left-Turn Percent per 1,320-ft Segment Length[2]					
		0	5	10	15	20	30
17,500	30						
	60						
	90						
22,500	30						
	60						
	90						
27,500	30						
	60	R	R	R			
	90	R	R	R	R	R	R
32,500	30	R	R	R	R	R	R
	60	R	R	R			
	90	R	R	R	R	R	
37,500	30	R	R	R	R	R	R
	60	R	R	R			T
	90	R	R	R	R		T
42,500	30	R	R	R	R	R	R
	60	R	R	R		T	T
	90	R	R	R			T

See Table 1 for Notes A and B.

-way left-turn lane.

Site-specific examination required.

R Consider adding a raised-curb median.

Volume levels may yield congested conditions.

Figure 14: When to consider converting from a 4-lane with TWLTL to a raised median
(Source: Bonneson and McCoy 1998)

Average Daily Traffic (vpd)	Active Access Point Density[1] (ap/mi)	Left-Turn Percent per 1,320-ft Segment Length[2]					
		0	5	10	15	20	30
17,500	30	U	U	U	U	U	
	60	U	U	U			
	90	U					
22,500	30	U					R
	60						R
	90					R	R
27,500	30			R	R	R	R
	60			R	R	R	R
	90		R	R	R	R	R
32,500	30		R	R	R	R	R
	60		R	R	R	R	R
	90		R	R	R	R	R
37,500	30		R	R	R	R	R
	60		R	R	R	R	R
	90	R	R	R	R	R	R
42,500	30	R	R	R	R	R	
	60	R	R	R	R	R	R
	90	R	R	R	R	R	R

Figure 15: When to consider converting from an undivided road 4-lane road to a raised median
(Source: Bonneson and McCoy 1998)

NCHRP Report 420 (Gluck, Levinson and Stover 1999) summarizes the crash prediction models developed in the last 25 years. The results of these models support the relative safety of the three different median types, which is:

- Safest: Raised median
- Safe: TWLTL
- Least safe: Undivided

They also support the 30 to 35% reduction in crashes found when converting from an undivided cross section to a TWLTL or raised median cross section. The raised median generally has the lowest predicted number of crashes, with the exception of the Harwood data mentioned in the report. The Bowman-Vecellio model suggests that the predicted number of crashes increases in a linear manner between an ADT of 10,000 and 40,000. The average of the various models generally results in fewer crashes for raised medians than for TWLTLs.

2.8 Design Considerations

Some of the design considerations for raised medians at intersections include:

- Length of turn/deceleration lane. Does it allow for safe deceleration and is it long enough for storage of vehicles?
- Minimum width of median at "nose." Is the nose visible?
- Visibility of the median. Is the median itself visible?
- Length of taper. Is the taper of the median appropriate for the approach speed? (CTRE 2003c)

In a similar volume related discussion CTRE (2003d) suggests when raised medians and TWLTLs should be considered from an operations standpoint. They recommend that a raised median should be considered when AADT is expected to exceed 28000 during the next 20 years or when it is difficult to predict future traffic volumes. Also, they report operations are typically better for raised medians than other cross-sections. On the other hand a TWLTL should be considered when AADT is 10000 to 28000, the percentage of turning volumes is high and the density of commercial driveways is low, and Reish and Lalani (1987) report TWLTLs have been successful on streets with 8,000 to 31,000 vehicles per day. However, the CTRE recommends that TWLTLs not be considered when traffic volumes are 24000 to 28000 and when commercial driveway densities are high and closely spaced because the number of conflict points increases.

As for speed criterion *A Policy on Geometric Design of Highways and Streets* (the Green Book) by AASHTO (2001) states that a "[TWLTL] works well where the speed on the arterial highway is relatively low (25 mph to 45 mph) and there are no heavy concentrations of left-turn traffic," and that a "[TWLTL] should be used only in an urban setting…where there are no more than two through lanes in each direction."

As for factors in selecting median width for a divided highway the following factors are considered (AASHTO 2001):

- Area type: rural or suburban
- Turning and through volumes from crossroads and vehicle mix
- Volume and vehicle mix for turns from the highway
- Design vehicle for crossing and turning
- Type of traffic control: signalized intersection, unsignalized intersection with potential to be signalized, unsignalized intersection with little potential for signalization
- Crossroad width and cross-section
- Left-turn treatment
- U-turns on divided highway

Median width is of another concern. Obviously increasing median width on divided highways provides multiple benefits when costs are not included in the discussion, including the following:

- Interference from opposing traffic is less
- Drivers feel more freedom
- More recovery area for out-of-control vehicles is available
- More green space is kept
- There will be less headlight glare
- There will be less need for median barrier
- Right of way is available for construction of additional lanes
- Right of way is available for left-turn lanes
- There will be adequate width available for median acceleration lanes
- U-turns of large vehicles can be accommodated

Table 8 presents feasible passenger car movements given particular median widths and the following statements summarize the relationship between median width and possible movements by passenger cars.

- 4 to 12 feet; not wide enough for left-turns
- 14 to 24 feet; wide enough for left-turn lane but not wide enough to store a crossing or turning passenger car and be clear of through traffic
- 26 to 44 feet; wide enough for turning or crossing passenger cars but not wide enough for a school bus
- 46 to 80 feet; wide enough for a school bus but not wide enough for a large truck
- more than 80 feet; wide enough for all AASHTO vehicles

Table 8: Feasible left-turn treatments for different median widths

Median Width (ft)	No Left-Turn Lane	Single Left-Turn Lane	Double Left-Turn Lane	Parallel Offset Left-Turn Lane	Tapered Offset Left-turn Lane
4	FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE
6	FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE
8	FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE
10	FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE
12	FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE
14	FEASIBLE	MARGINAL	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE
16	FEASIBLE	MARGINAL	NOT FEASIBLE	MARGINAL	NOT FEASIBLE
18	FEASIBLE	FEASIBLE	NOT FEASIBLE	MARGINAL	MARGINAL
20	FEASIBLE	FEASIBLE	NOT FEASIBLE	MARGINAL	MARGINAL
22	FEASIBLE	FEASIBLE	NOT FEASIBLE	MARGINAL	MARGINAL
24	FEASIBLE	FEASIBLE	MARGINAL	MARGINAL	MARGINAL
26	FEASIBLE	FEASIBLE	MARGINAL	FEASIBLE	FEASIBLE
28	FEASIBLE	FEASIBLE	MARGINAL	FEASIBLE	FEASIBLE
30	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE
32	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE
34	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE
36	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE
38	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE
40 and over	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE

(Source: Harwood et al. 1997)

2.9 Summary

There are many helpful reports available for the state engineers to reference to. This chapter presented the findings for major issues related to using a particular type of median. The following references were found to be especially useful for writing this chapter.

- For design: NCHRP 395 (Bonneson and McCoy 1997), Florida DOT's Median Handbook (1997), TTI Report 1846 (O'Shea et al. 2000)
- Selecting a median treatment: NCHRP 395 (1997), Access Management Manual (TRB 2003)
- Comparing median types: NCHRP 420 (Gluck, Levinson and Stover 1999), Squires and Parsonson, (1989), Oregon DOT Median Guidelines (Transportation Research Institute 1997)
- Economic Impact: TTI Report 3904 (Eisele and Frawley 2000)

3. CUSTOMER AND STORE MANAGER SURVEYS

3.1 Introduction

University Parkway is an arterial that extends from 900 East in Provo to Geneva Road in Orem and intersects Interstate 15 (Exit 272) on the west side of Orem near Utah Valley State College (UVSC). There is a business district on the arterial in Orem and Provo with strip malls of mostly large businesses and restaurants. In 2002, a raised median was installed along this stretch between 400 W and 200 E in Orem in order to reduce the number of severe crashes in this stretch. Before the raised median was built in this segment, there were three lanes in each direction with a painted median which was not to allow traffic across. Being a painted median, it did not adequately block vehicles from turning into and out of the median. Due to an increasing number of fatalities and other serious crashes the raised median was installed. In general many business owners believe that raised medians negatively affect their businesses. To ascertain the effect of the raised median between 400 w and 200 E on University Parkway in Orem on the businesses and customers owner and customer surveys were conducted to ascertain the effect of the raised median on the businesses. This chapter presents the findings of these two surveys. These surveys were done because UDOT desired to know the impact of the raised median on businesses and customers in Utah.

3.2 Methodology

Two surveys were created: one for the customers and the other for the managers of the businesses. Copies of these surveys can be found in Appendices B and C. A similar survey was done in Texas by Frawley and Eisle (2001), and our survey questions are similar to those questions but tailored to the unique characteristics of University Parkway.

The customer survey has eleven questions. These eleven questions were aimed at answering five key questions, which are:

1. Have driving maneuvers changed when going into or out of a business?
2. If so, does this change in driving maneuver affect the likelihood of returning for business?
3. Was the trip planned or pass-by?
4. What is most important to the customers by ranking from 1 to 6, the importance of these six considerations, with 1 being most important:
   - Distance to travel
   - Hours of operation
   - Customer service
   - Product quality
   - Product price
   - Accessibility to store
5. What effect does the raised median have on traffic congestion, traffic safety, property access, and customer satisfaction? Are these factors better, worse, or the same?

The manager survey has nine questions, and they are aimed at knowing the following things:

1. Opinion of how much business is pass-by versus planning to stop.
2. Opinion of whether customers are less likely to frequent the business because of the raised median.
3. Opinion of what is most important to customers by ranking (same as item 4 for the manager survey)
4. Opinion of how traffic congestion, traffic safety, property access, business opportunities, customer satisfaction, and delivery convenience have been affected (better, worse, or about the same) by the raised median.
5. Number of full-time and part-time employees before, during and after construction of the raised median
6. How has the number of customers per day, full-time employees or part-time employees changed during and after construction of the raised median? Has there been a percent increase, percent decrease, no change, or not sure?

3.2.1 Identifying the business

It is important to identify the business in some way other than the actual name, so that any information received from managers concerning their employees and customers can be kept confidential. In order to do this, each store has been put into a category depending on its type of business. For example, instead of using the name Golden Corral, we code it with "restaurant". Fourteen different types of businesses were created after categorizing the businesses between 400 W and 200 E of University Parkway of Orem, UT:

1. bank
2. clothing
3. dealership
4. electric
5. entertainment
6. financial
7. home
8. hospital
9. office
10. restaurant
11. specialty
12. toys
13. appliance
14. book

The customer surveys are also represented in this way. The goal for the manager and customer surveys was to get representation from each type of business.

It was necessary to determine the type of business because businesses can be classified into two categories: pass-by oriented and planned stop oriented business. Some businesses depend on pass-by traffic and some depend on planned stop traffic. If a business is dependant on pass-by traffic, such as a fast-food restaurant or gas station, then its location is very important so that customers can easily enter and exit the business as they are passing by the store. However, if the business is dependent on customers making planned stops, such as a hardware store or furniture store, then its location does not have to be easily accessible because customers are not deterred by the easiness of getting to the business because they have a specific reason to reach planned stop oriented businesses.

If we know the type of business, such as bank or clothing store, then we can determine whether it is going to be a pass-by or planned stop business. It turns out that all of the businesses on the study segment of University Parkway can be justifiably classified as a planned stop business.

Not all businesses agreed to take the survey because their store policies did not allow us to administer the survey at those businesses. Out of the fourteen business types, twelve responses from eight business types were represented in the returned surveys:

- bank (1)
- clothing (1)
- dealership (1)
- financial (3)
- home (2)
- restaurant (2)
- hospital (1)
- book (1)

3.2.2 Collecting the surveys

Customer and manager surveys were administered differently. With the customer surveys, a call was made to the businesses in which we would like to conduct a survey of the customers. If the manager gave permission, then we set up a time to conduct surveys outside of the business. Survey takers would stand outside of the business as customers entered and ask if they would like to participate in a survey. If they were willing then we asked them the questions and filled out the survey for them as they answered. In all 173 customer surveys were collected.

With the manager surveys, a call was made to the manager and the manager fill out a manager about their business in the last few years, before and after the raised median was built. As mentioned in the previous section many times the business declined our request per company policy, so our representation was limited to eight of the fourteen business types. If they accepted, then we either faxed them a survey or dropped it off at their business. There were eleven completed and one partially completed surveys that were collected.

3.3 Results

Of the 173 customer surveys collected, there were 11 that came from a financial business, 84 that came from a clothing business, and 78 from a home business. Thus, there were three types of businesses represented by the customer surveys. Eleven manager surveys were collected. Eight business types were represented. Due to the small number of respondents, some business types had only one response.

This section presents the findings of these two surveys.

3.3.1 Customer survey

First descriptive statistics and short analyses of the eleven questions are presented, followed by their implications. Please note that 174 customers participated in the survey.

Q1. 55% were aware that a raised had been built in 2002 and 45% were not aware that it had been built. 170 customers answered this question

Q2. 67% had patronized the business before while 33% had not patronized the business before. 166 customers answered this question

Q3. 37% will have to make a U-turn or series of right turns to get to their next destination, while 63% will not have to make one of these maneuvers. 168 customers answered this question

Q4. 48% of those that patronized this business before the raised median was built now have a different driving maneuver when they leave, while 52% have the same driving maneuver as before. 111 customers answered this question

Q5 & Q7. With respect to the raised median, 83% said they were just as likely to patronize the business as before the raised median was built, while 14% were less likely, and 3% were more likely. 142 customers answered this question.

Q6. 79% of the customers were making a planned stop while 21% were pass-by. 165 customers answered this question. It was found that the percent of special-trip and passing-by customers did not change statistically between the three business types, after conducting a chi-square analysis at a 95% confidence level.

Q10. When selecting a business type, customers ranked the following considerations. Number one is the most important reason to choose a particular business and number six is the least important reason. 141 customers ranked the considerations. Product price was given a number one ranking most often, and accessibility to store was the least important of these six items.

1. Product Price
2. Product Quality
3. Customer Service
4. Distance to travel
5. Hours of operation
6. Accessibility to store

Q11. Table 9 summarizes the responses by the customers. The number of responses to each item represents the number of responses for each item.

Table 9: Percent of customers that felt the items below were made better, worse, or the same

	Traffic Congestion (165)	Traffic Safety (166)	Property Access (166)	Customer Satisfaction (162)
Better	15	49	7	10
Worse	33	20	58	19
Same	52	31	34	70

The feelings of how traffic congestion and traffic safety were affected by the raised median were similar among the different customer groups, according to a chi-square test at a 95% confidence level.

In summary, about one third of the surveyed customers now make a U-turn or series of right turns to get to their next destination, indicating the raised median in the study segment of University Parkway affected travel patterns of some of the customers. 48% of those that had patronized the business before raised median construction had to modify their driving maneuvers because of the raised median. Despite these changes a very large percent of the customers (83%) said they were just as likely to visit the business even with the raised median. Moreover, only one-fifth of the customers that frequented the businesses were pass-by customers. When choosing a business, accessibility to store was the least important to the surveyed customers, while factors that would concern the customers most were product price, product quality, and customer service. One-third of surveyed customers believed that the raised median made traffic congestion worse, while half believed traffic safety improved. More than half believed that property access got worse, and seven out of ten felt customer satisfaction did not change. In summary, it can be said that the customers think their purchasing habits would not significantly change in this segment of University Parkway even though the raised medians may force them to change their travel patterns and traffic congestion might have resulted. This is understandable given most of the businesses on this segment of University Parkway are catering special-trip customers.

3.3.2 Manager Survey

First descriptive statistics and short analyses of the eleven questions are presented in the order of questions, followed by their implications. Please note that eleven store managers responded out of twelve businesses located in the studied segment of University Parkway.

About 20% of businesses on University Parkway where the raised median was built in 2002 participated in this survey.

Q1. The year that businesses began operations was meant to screen out businesses that began after the raised median installation.

Q2. The average estimated percent of pass-by and planned stop traffic is 15% and 85%, respectively.

Q3. The managers were asked whether their regular customers were less likely or more likely to come to their business due to the raised median, or were they just as likely as before. Table 10 shows the distribution of customer satisfaction level as evaluated by store managers.

Table 10: Percent and number of managers that felt customers were less, same, or more likely to come to their business due to raised median

Less	Same	More
2	9	1
17%	75%	8%

Q4. The managers ranked the considerations as shown below, with number one being the most important reason a customer chooses their store and number six is the least important. Customer service, product quality and product price were all ranked number 1 most often and customer service was also ranked number 2 most often. The other factors were ranked as shown below.

1. Customer service, product quality, product price
2. Customer service
3. Distance to travel, product price
4. Distance to travel, hours of operation
5. Accessibility to store
6. Hours of operation

Q5. Each manager was asked whether traffic congestion was made better, worse, or the same by the raised median. The percent of managers that gave a particular response for each consideration is given in Table 11. All 12 managers responded.

Table 11: Percent that managers felt each consideration was made better, worse or same

	Traffic Congestion	Traffic Safety	Property Access	Customer Satisfaction	Business Opportunities	Delivery Convenience
Better	8	75	8	0	0	0
Worse	8	0	50	33	25	42
Same	83	25	42	67	75	58

Q6. Each manager estimated how many full-time and part-time employees were working at their business. The average number of employees for all businesses is given for each year in Table 12.

Table 12: Average number of employees each year at each business

	1997	1998	1999	2000	2001	2002	2003
Full-time	45	47	49	44	46	41	42
Part-time	3.33	3	3	2.67	2.33	4.5	4.5

Q7. Managers were asked whether there was a percent increase, decrease, or no change in their number of customers per day, full-time employees, and part-time employees during construction and after construction of the raised median. From the responses, a 95% confidence interval was developed for the percent change. Negative is percent decrease and positive is percent increase. Table 13 shows the 95% confidence intervals of the percent change based on manager responses.

Table 13: 95% confidence intervals of the percent change based on manager responses

	During construction	After Construction
Customers per day	(-6.95, 0.70)	(-5.50, 1.83)
Full-time employees	(-13.88, 5.63)	Not Analyzed
Part-time employees	(0,0)	(0,0)

In summary, managers estimated that 85% of their business was from planned stops. Also, 75% of managers believed that their customers were just as likely to visit their store due to the raised median. Furthermore, distance to travel, hours of operation, and accessibility to store were believed to be least important to customers, while product quality, customer service, and product price were the most important to them.

Traffic safety was the only item that the majority of managers felt raised medians had improved. The majority of managers believed that traffic congestion, customer satisfaction, and business opportunities had not been significantly affected. About half of the twelve managers believed that customer satisfaction and delivery convenience had worsened. For the most part, the majority of the twelve managers believed that the considerations in Table 11 had either gotten better or stayed the same, except for property access.

There does not seem to be any pattern in the number of full-time or part-time employees as shown in Table 12. However the managers felt that the number of customers per day during and after construction may have slightly decreased, while the number of full-time employees during construction may have slightly decreased. There seems to be no change in the number of part-time employees.

The data set in the manager survey is only twelve. This is a very small number to make useful predictions or analyses. Tables 12 and 13 may not be very useful for this reason. In Table 12, the standard deviation is very large for both full-time and part-time employees. The responses used to base the 95% confidence intervals seemed to be subjective and based on perceived changes.

What this survey implies is that most managers do not perceive a change in the volume of business. Also, the factors that affect customers the most are something that businesses have control over, such as customer service, product quality and product price. Over all, most managers felt that traffic safety had improved since the installation of the raised median, which was the most important reason to install a raise median at this section of University Parkway. The other factors seem to be an inconvenience but are not as important as traffic safety for the managers.

3.3.3 Comparing customer and manager surveys

Four questions were similar between the customer and manager surveys. They are:

- What is the percent planned stop versus pass-by?
- Are customers less, more, or just as likely to visit a business due to the raised median?
- Rank each consideration (distance to travel, hours of operation, etc.) from most important to least important when selecting a business of one type.
- Were certain considerations (traffic congestion, traffic safety, etc.) made better, worse, or the same by the raised median?

The percent of pass-by versus planned stop customers is compared in Table 14.

Table 14: Percentage of planned stop versus pass-by customers

	Pass-by	Planned Stop
Customers	21%	79%
Managers	15%	85%

The likelihood of customers going to a particular store due to the raised median is given in Table 15. More than 85% of the surveyed customers and managers indicated the same or the more. About one in six survey participants felt they are less likely to come to the store because of the raised median.

Table 15: How likely are customers to come to the store because of the raised median

	Less	Same	More
Customers	14%	83%	3%
Managers	17%	75%	8%

The rank of most important considerations when going to a store is given in Table 16 shown below. "Accessibility of store" turned out to be at the bottom rank of the concerned items for customers and only 5th of the concerned items for managers.

Table 16: Ranking of most important considerations when going to a store

Rank	Customers	Managers
1	Product Price	Product Quality
2	Product Quality	Customer Service
3	Customer Service	Product Price
4	Distance to Travel	Distance to Travel
5	Hours of Operation	Accessibility to Store
6	Accessibility to Store	Hours of Operation

Managers and customers are asked whether certain considerations are better, worse, or stayed the same. Table 17 shows the results of this analysis.

Table 17: Customers and managers opinion of whether certain considerations have been made better, worse or the same

		Traffic Congestion	Traffic Safety	Property Access	Customer Satisfaction
Customers	Better	15	49	7	10
	Worse	33	20	58	19
	Same	52	31	34	70
Managers		Traffic Congestion	Traffic Safety	Property Access	Customer Satisfaction
	Better	8	75	8	0
	Worse	8	0	50	33
	Same	83	25	42	67

In summary, the percent of customers that made special stops is slightly less than what was estimated by the manager surveys. Also, a larger percent of customers said the likelihood of visiting a store has not changed by the raised median.

The three most important and least important items to consider when selecting a store is the same for customers and managers. The three most important considerations are product price, product quality, and customer service, while the three least important items are distance to travel, hours of operation, and accessibility to store. Product price is most important to customers while managers felt that product quality was most important to customers. Also, accessibility to store is slightly less important than what managers perceived.

A large percentage of managers felt that traffic safety had improved for customers by the presence of a raised median, and one-fifth of all customers felt that traffic safety was actually worse. Also, a large percentage of customers felt that traffic congestion was worse. Furthermore, customers felt that property access was slightly worse than what managers had believed to be true of customers. Perhaps the differences in numbers are because customers are more sensitive to the changes in traffic control than the managers. Moreover, ten percent of customers thought customer satisfaction was better while managers thought otherwise. Many customers liked the raised median because of safety despite the decline in convenience.

It should be noted that the surveys collected for the customers were from only three locations, that is, three business types, while the surveys collected from the managers were from twelve stores. The types of stores representing the customer surveys were clothing, financial, and furniture. The types of stores represented from the manger surveys were clothing, furniture, financial, medical, restaurant, book, and dealership.

Survey respondents were encouraged to add comments on the survey forms. Appendix D contains comments from the customer and manager surveys.

4. CRASH EXPERIENCE: BEFORE AND AFTER INSTALLATION OF RAISED MEDIAN

Many previous research studies in journals suggest that raised medians improve safety. However, most of these findings are from other states; therefore, the Utah Department of Transportation has requested a study of crash data on four arterials where raised medians were installed in the past few years.

The purpose of this study is to determine what noticeable effects that a raised median has on crashes. The main questions are:

- Do raised medians reduce severity of crashes?
- Do raised medians reduce the frequency of crashes?
- Do raised medians increase or decrease certain types of collisions?

Each arterial is different and there are many things other than an installation of a raised median that could affect crash severity, frequency of crashes, and certain types of collisions as raised medians are usually not installed alone but with other road improvements. Therefore, recognize that raised medians may not be the only reason that could change crash dynamics.

The roads that are studied are located in Salt Lake County and they are:

- State Road 186, State Road 89 to 1300 East
- State Road 89, 10200 South to 10600 South
- State Road 89, 300 South to North Temple
- State Road 68, 5400 South to 6200 South

Before and after statistics were compared for four different crash statistics:

- Crash rates
- Location of crashes
- Severity of crashes
- Collision types

Three crash rates are used to compare the data:

- crash rate – crashes per 100 million vehicle miles (MVM) or 100 million entering vehicles (MEV)
- crashes per mile – number of crashes divided by length of segment
- crash percent (%) – specific percent of total crashes

Note that all crash rates 'before' and 'after' are the annual average of the number of years before or after the construction of the raised median segment where data are available. Due to the insufficient dataset either 'before' or 'after cases, rigorous statistics cannot be made. The findings presented here should be cautiously interpreted.

The data used in this crash analysis was extracted from UDOT's accident website, which is the property of the UDOT Division of Traffic and Safety.

4.1 Highway 186 (400 S or 500 S), SR 89 to 1300 East

A raised median was installed on Highway 186 between SR 89 and 1300 East during the years 1999 to 2001. ‘Before’ crash statistics were collected from 1992 to 1998, while ‘after’ crash statistics were collected in 2002. The ‘before’ crash statistics were averaged together, but the ‘after’ crash statistics were not averaged because it comprises of just one year of data. The average AADT ‘before’ and ‘after’ is 42,857 and 49,594, respectively.

This is a unique raised median because it also serves as the location of train tracks for the light rail system (TRAX) in Salt Lake City.

Crash rate per mile, at one signalized intersection and the midblock are displayed in Table 18.

Table 42: Crashes on Highway 186

	Before	After
Crashes per mile*	52	32
Signalized intersection at Hwy 89 (Per 100 MEV)	16	6
Midblock (Per 100 MVM)	313	344

* Length of segment: 1.9 miles

Signalized intersection and midblock crash percentages are displayed in Table 19.

Table 43: Signalized intersection and midblock crash percentages on Highway 186

	Before (%)	After (%)
All signalized intersections	64	54
Midblock	36	46

Crash severity statistics at the midblock are displayed in Table 20.

Table 44: Crash severity rate and percent on Highway 186 at the midblock

	Per 100 MVM		%	
	Before	After	Before	After
fatalities	0	25	0	7
broken bones	17	12	5	4
bruises/abrasions	27	49	9	14
possible injury	77	98	25	29
no injury	192	160	61	46

Crash severity rates at one intersection where both roads are state routes are displayed in Table 21.

Table 45: Crash severity rate at the signalized intersection of Highways 186 and 89

	Per 100 MEV	
	Before	After
fatalities	0	0
broken bones	5	0
bruises/abrasions	5	6
possible injury	5	0
no injury	1	0

Crash severity percentages for all intersections are shown in Table 22.

Table 46: Crash severity percentages for all intersections

	Before (%)	After (%)
fatalities	0	3
broken bones	13	6
bruises/abrasions	16	20
possible injury	29	34
no injury	41	37

Collision type statistics at the midblock are displayed in Table 23.

Table 47: Collision type crash rate and percent on Highway 186 at the midblock

	Per 100 MVM		Percent (%)	
	Before	After	Before	After
rear end	108	86	40	27
right angle	18	12	7	4
sideswipe	30	25	11	8
same direction	19	12	7	4
u-turn	0	0	0	0
backing	6	0	2	0
single vehicle	59	184	22	58
angle	27	0	10	0
other	0	0	0	0

Collision type crash rates at one intersection are shown in Table 24.

Table 48: Collision type crash rates at the intersection of highways 186 and 89

	Per 100 MEV	
	Before	After
rear end	2	6
right angle	8	0
sideswipe	0	0
same direction	0	0
uturn	0	0
backing	0	0
single vehicle	2	0
angle	0	0
other	0	0

Collision type crash percentages for all intersections are given in Table 25.

Table 49: Collision type crash percentages for all intersections

	Before (%)	After (%)
rear end	25	43
right angle	35	20
sideswipe	2	0
same direction	2	3
uturn	2	3
backing	2	0
single vehicle	8	20
angle	25	9
other	0	3

The reader must interpret the following comments cautiously because the 'after' data contains only one year of data.

In an overall summary, crashes per mile decreased by 20 after raised median construction (Table 18). Also, crashes per 100 MEV decreased from 16 before construction to 6 after construction (Table 18) at the intersection of highways 186 and 89, while the midblock crash rate increased from 313 to 344 (Table 18). Moreover, the percentage of crashes at signalized intersections decreased from 64% to 54%, while midblock crashes increased from 36% to 46% of all crashes (Table 19).

Taking a look at the severity of crashes, fatality rate increased from 0 to 25 per 100 MVM at the midblock, while crashes resulting in broken bones or bleeding wounds decreased from 17 to 12 per 100 MVM (Table 20). Unfortunately, fatalities represented 7% of all accidents after raised median construction (Table 20), however, this is based on one year of data. Hence, information is insufficient. At the intersection of highways 186 and 89, there were no fatalities and crashes resulting in broken bones or bleeding wounds decreased from 5 to 0 per 100 MEV (Table 21). Moreover, the percent of fatal crashes at all intersections after construction was 3%, up from 0% (Table 22). The second most severe crash type decreased in percent from 13% to 6% for all intersections.

Now looking at collision type, all collision types decreased in rate and percent except single vehicle crashes, at all midblock segments (Table 23). Rear end crash rate decreased from 108 to 86 per 100 MVM; right angle crashes decreased from 18 to 12; sideswipe from 30 to 25; same direction (merging/diverging) crashes from 19 to 12; backing from 6 to 0; and angle crashes from 27 to 0 (Table 23). Before construction, rear end crashes (40%) were the most common, while single vehicle crashes (22%) were second most common. After construction, single vehicle crashes (58%) were most common, while rear end crashes (27%) were second most common (Table 23). At the intersection of highways 186 and 89, right angle and single vehicle crash rates decreased from 8 to 0 per MEV and 2 to 0 per MEV, respectively; while the rear end crash rate increased from 2 to 6 per MEV (Table 24). For all intersections, rear end crashes and single vehicle crashes increased in percent from 25% to 43% and 8% to 20%, respectively, out of all intersection crashes (Table 25). On the other hand, right angle crashes and angle crashes decreased in percent from 35% to 20% and 25% to 9%, respectively (Table 25).

In regards to severity, there were three fatalities in 2002 that made the fatality rates and percent very high. It is unfortunate that three fatalities occurred in the same year, but each of the crashes is a result of careless driving or careless pedestrians, not the raised median. One fatality occurred because an 82 year old person did not cross the street at an intersection and was hit by an oncoming vehicle. A second fatality occurred because two young kids were traveling too fast in a motorcycle and hit the curb as they ran off the road to the right and flipped the vehicle. The last fatality occurred at an intersection because one driver disregarded a traffic signal and hit an oncoming vehicle.

Other than the high fatality rates and percentages, the rate of crashes resulting in broken bones or bleeding wounds, dropped from 17 to 12 per 100 MVM at midblock segments and 5 to 0 per 100 MEV at the intersection of highways 186 and 89 (Tables 20 and 21). Crashes resulting in broken bones or bleeding wounds also dropped in percentage of total crashes. It dropped from 5% to 4% at the midblock and 13% to 6% at signalized intersections (Tables 20 and 22). Less severe crashes increased in rate and percent (Tables 20, 21 and 22), which may mean that crashes are shifting from being more severe to less severe, and may be attributed to the raised median.

In regards to collision types, some trends are emerging in the data. It appears that rear end crashes are decreasing at the midblock and increasing at signalized intersections. It also appears that right angle and angle only crashes are decreasing in rate and percent at both midblock and signalized intersection locations. However, it appears that single vehicle crashes are increasing at the midblock and intersection. Perhaps the following explanation can give insight into these trends.

First, rear end crashes are less likely when vehicles are not stopping and going all the time. With raised medians, vehicles are less likely to stop and go, which makes rear end collisions less likely. Second, the raised median also does not permit vehicles to make crossing movements except at the intersection or midblock openings. This prevents right angle and other angle crashes to occur as much. Lastly, single vehicle crashes are more likely when there is a concrete divide in the middle of the road. These crashes are not likely to be serious, but they tend to occur more often.

4.2 Highway 89 (State Street), 10200 South to 10600 South

A raised median was installed on Highway 89 between 10200 South and 10600 South, next to the South Towne Center in 1994. 'Before' data were gathered from 1992 to 1993, while 'after' data were gathered from 1995 to 2002. In this case, the amount of 'before' data is much less than the 'after' data. The average AADT 'before' and 'after' is 17,603 and 20,462, respectively.

Crash rate per mile and at the midblock are displayed in Table 26.

Table 50: Overall crash rates on Highway 89, 102nd to 106th South

	Before	After
Crashes per mile*	30	113
Midblock (Per 100 MVM)	464	694

* Length: 0.5 miles

Crash percentages occurring at the midblock and signalized intersections are shown in Table 27.

Table 51: Midblock and signalized intersection crash percentages on Highway 89, 10200 S to 10600 S

	Before (%)	After (%)
Signalized intersections	0	53
Midblock	100	47

Crash severity statistics at the midblock are displayed in Table 28.

Table 52: Crash severity rates and percentage on Highway 89, 10200 S to 10600 S, at the midblock

	Per 100 MVM		Percent (%)	
	Before	After	Before	After
fatalities	17	0	4	0
broken bones	83	18	18	3
bruises/abrasions	17	21	4	3
possible injury	99	231	21	33
no injury	248	424	54	61

Crash severity percentages at all intersections are shown in Table 29.

Table 53: Crash severity percentages at all intersections on Highway 89, 10200 S to 10600 S

	%	
	Before	After
fatalities	0	0
broken bones	0	5
bruises/abrasions	0	15
possible injury	0	35
no injury	0	45

Collision type crash rate and percent at the midblock are shown in Table 30.

Table 54: Collision type crash rates and percentages on Highway 89, 10200 S to 10600 S, at the midblock

	Per 100 MVM		Percent (%)	
	Before	After	Before	After
Rear end	33	463	8	67
Right angle	99	53	24	8
Sideswipe	99	85	24	12
Same direction	17	11	4	2
U-turn	17	18	4	3
Backing	0	4	0	1
Single vehicle	50	50	12	7
Angle	66	11	16	2
Other	33	0	8	0

Collision type percentages at all intersections are shown in Table 31.

Table 55: Collision type percentages at all intersections

	Before (%)	After (%)
Rear end	0	27
Right angle	0	55
Sideswipe	0	3
Same direction	0	1
U-turn	0	3
Backing	0	2
Single vehicle	0	2
Angle	0	6
Other	0	1

Looking at Table 26 of the overview, there were almost four times more accidents per mile after the raised median was constructed then before. The construction of the raised median coincides with the construction of the South Towne Center Mall, which attracts many trips each day. Also, there are many other establishments such as restaurants and big box stores that create a headache for drivers. When looking at only the midblock, the crash rate increased from 464 to 694 crashes per 100 MVM (Table 26). This represents a 50% increase in crash rate. Moreover, the percentage of crashes at signalized intersections increased from 0% to 53%, but midblock crash percentage decreased from 100% to 47% (Table 27). There probably were not any signalized intersections along this segment of the highway before the raised median was constructed. This explains why there were no crashes at signalized intersections 'before'.

As far as severity of crashes, the two most severe crash types decreased in rate and percent at the midblock (Table 28). The fatality rate decreased from 17 to 0 per 100 MVM, while crashes resulting in broken bones and/or bleeding wounds decreased from 83 to 18 per 100 MVM. Out of all crashes, the percent of fatal crashes decreased from 4% to 0%, and the percent of crashes resulting in broken bones and/or bleeding wounds decreased from 18% to 3%. Clearly, the midblock is a much safer place to drive now, than before the raised median was constructed.

There were no fatalities at intersections after raised median construction (Table 29). Crashes at signalized intersections resulting in broken bones and/or bleeding wounds were 5% after raised median construction. This is a fairly low percent. Unfortunately, it cannot be compared with before construction because there were no signalized intersections before construction.

The majority of collision type crashes decreased in rate and percent at the midblock (Table 30). However, rear end, u-turn, and backing collisions showed an increase in crash rate. Rear end, u-turn, and backing collisions showed an increase from 33 to 463, 17 to 18, and 0 to 4 per 100 MVM, respectively. Rear end collisions showed a very large increase in rate, while the other two types showed very modest increases. Out of all crashes, rear end crashes also shows a very large increase in percentage, by increasing from 8% to 67%. This may be attributed to increased traffic reaching near capacity of the road.

Besides the head-on collision, the most serious type of collision is the right angle. The right angle collision decreased in rate and percent at the midblock (Table 30). The collision rate decreased from 99 to 53 per 100 MVM, and the percent decreased from 24% to 8%. Angle accidents are also serious. They decreased in rate and percent as well – from 66 to 11 per 100 MVM and from 16% to 2%. Raised medians are effective at reducing movements that result in right angle or angle collisions at the midblock, which is why these serious collisions have lowered in percent.

The two most common types of collisions at the midblock before construction were right angle (24%) and sideswipe (24%). After construction, the two most common collision types are rear end (67%) and sideswipe (12%).

Shifting gears to signalized intersections, right angle (55%) and rear end (27%) collisions are the most common after construction (Table 31). Unfortunately, this cannot be compared to before construction. Right angle crashes are generally more common at signalized intersections, stop signs, and unsignalized intersections, because vehicles are traveling in perpendicular directions.

In retrospect, the overall trends are that many more crashes are occurring, due to the South Towne Center and other businesses in the area that generate a large amount of traffic. The midblock crash rate has increased as well. Crashes at the midblock versus signalized intersections are about equal in percent. As far as collision type, right angle crashes have been cut in half and angle crashes have reduced markedly. However, rear end collisions showed a large increase.

Furthermore, safety has improved dramatically, as fatalities and broken bone crashes have decreased both in rate and percent share of total crashes.

4.3 Highway 89 (State Street), North Temple to 300 North

A raised median was installed on Highway 89 between North Temple and 300 North in 1998. Before data were gathered from 1992 to 1997, while after data were gathered from 1999 to 2002. This site has compatible amounts of 'before' and 'after' data. The average AADT 'before' and 'after' is 13,865 and 11,965, respectively.

Crash rate per mile, at one signalized intersection and the midblock are displayed in Table 32.

Table 56: Overall crash rates on Highway 89, N Temple to 3rd North

	Before	After
Crashes per mile*	30	28
Signalized intersection at Hwy 186 (Per 100 MEV)	11	94
Midblock (Per 100 MVM)	442	198

* Length: 0.3 miles

Crash percentages of all signalized intersections and the midblock are shown in Table 33.

Table 57: Signalized intersection and midblock crash percentages on Highway 89, N Temple to 300 North

	Before (%)	After (%)
All signalized Intersections	26	68
Midblock	74	32

Crash severity rates and percentages at the midblock are displayed in Table 34.

Table 58: Crash severity rates and percentages on Highway 89, N Temple to 300 N, at the midblock

	Per 100 MVM		Percent (%)	
	Before	After	Before	After
fatalities	0	0	0	0
broken bones	66	0	15	0
bruises/abrasions	99	19	23	10
possible injury	110	95	25	50
no injury	165	76	38	40

Crash severity rates at one intersection are displayed in Table 35.

Table 59: Crash severity rates at the intersection of highways 89 and 186

	Per 100 MEV	
	Before	After
fatalities	0	0
broken bones	11	16
bruises/abrasions	11	83
possible injury	25	36
no injury	11	36

Crash severity percentages at all signalized intersections are displayed in Table 36.

Table 60: Crash severity percentages for signalized intersections

	Before (%)	After (%)
fatalities	0	0
broken bones	19	9
bruises/abrasions	19	48
possible injury	44	21
no injury	19	21

Collision type crash rates and percentages at the midblock are displayed in Table 37.

Table 61: Collision type rate and percent on Highway 89, 10200 S to 10600 S, at the midblock

	Per 100 mvm		Percent (%)	
	Before	After	Before	After
rear end	187	286	32	58
right angle	121	76	21	15
sideswipe	33	57	6	12
same direction	11	38	2	8
uturn	11	0	2	0
backing	0	0	0	0
single vehicle	176	19	30	4
angle	44	19	8	4
other	0	0	0	0

Collision type crash rates at one intersection are displayed in Table 38.

Table 62: Collision type rate at the intersection of highways 89 and 186

	Per 100 MEV	
	Before	After
rear end	4	36
right angle	4	10
sideswipe	0	10
same direction	0	5
uturn	0	5
backing	0	0
single vehicle	4	0
angle	0	26
other	0	0

Collision type crash percentages at all signalized intersections are displayed in Table 39.

Table 63: Collision type percent for all signalized intersections

	Percent (%)	
	Before	After
rear end	50	58
right angle	19	15
sideswipe	0	12
same direction	0	8
uturn	0	0
backing	0	0
single vehicle	25	4
angle	6	4
other	0	0

In the overview, the average number of crashes per mile did not change much after construction of the median (Table 32). However, there was a change in where these crashes took place. The midblock crash rate decreased considerably from 442 to 198 per 100 MVM (Table 32). One representative signalized intersection at Highway 186 showed a large increase in crash rate – from 11 to 94 per 100 MEV (Table 32). The percent of crashes at signalized intersections versus the midblock switched. The percentage of crashes at signalized intersections increased from 26% to 68%, while the midblock crashes decreased from 74% to 32% (Table 33). So, crashes were decreasing at the midblock and increasing at signalized intersections.

Another important factor for consideration is the severity of the crashes. There were no fatalities on this stretch before or after (Table 34). However, it appears that the severity of crashes is going down because crashes resulting in broken bones and/or bleeding wounds decreased in rate and percent from 66 to 0 per 100 MVM and from 15% to 0% of all crashes.

Crashes resulting in bruises and abrasions also decreased in rate and percent from 99 to 19 per 100 MVM and from 23% to 10% of all crashes.

The signalized intersection of highways 89 and 186 showed a little different trend. There were also no fatalities before or after, but crashes resulting in broken bones and/or bleeding wounds rose slightly (Table 35). On the other hand, Table 36 shows that the percentage of crashes resulting in broken bones and/or bleeding wounds dropped from 19% to 9% at all signalized intersections.

The next category to look at it is collision type. Like the previous two highway segments, rear end crash rates and percentages increased while right angle and angle crash rates and percentages decreased at the midblock (Table 37). Rear end crash rates increased in rate and percent from 187 to 286 per 100 MVM and 32% to 58%, respectively. Right angle crash rates decreased from 121 to 76 per 100 MVM, while the percentages decreased from 21% to 15%. Angle crash rates also decreased from 44 to 19 per 100 MVM, while the percentages decreased from 8% to 4%. Two changes occurred relative to the first two highway segments. Sideswipe and same direction collisions both increased in rate and percent (Table 37). It is also interesting to note that single vehicle collisions decreased dramatically in rate and percent (Table 37), which is in stark contrast to the change that occurred on Highway 186 (Table 23).

Moving on to the intersection of highways 89 and 186, the crash rates of all collision types increased except single vehicle collisions (Table 38). The largest increases in rate at this intersection are rear end and angle collisions. Again, it appears that raised medians are associated with an increase in rear end collisions, as was the case with the raised median segment on Highway 186 (Table 24). Raised medians naturally increase the crash rates at midblock openings and signalized intersections because movements across the raised median are restricted. This intersection is a very busy intersection and may not represent the effects of raised medians on intersections accurately.

Looking at all signalized intersections in this site, rear end, same direction and sideswipe collisions increased, while right angle, single vehicle and angle collisions decreased (Table 39). It is encouraging to find that right angle and angle crash percentages decreased because these are usually the most serious types of crashes. They also decreased at signalized intersections on Highway 186 (Table 25). Single vehicle collisions continue to show no trend in the data. On Highway 186 there was a large increase (Table 25), on Highway 89 from 10200 S to 10600 S the change up or down cannot be determined (Table 31) and on this highway there was a large decrease (Table 39).

In summary, crashes are shifting from the midblock to the signalized intersections; crashes are becoming less serious at both the midblock and the signalized intersections; and right angle, single vehicle, and angle collisions are decreasing, while less serious collisions are increasing. These changes have happened while the average number of crashes significantly changed.

4.4 Highway 68 (Redwood Road), 5400 South to 6200 South

A raised median was installed on this segment in 1994 and 1995. Before data were gathered from 1992 to 1993, while after data were gathered from 1996 to 2002. This raised median extends under Interstate 215. Note that the before data has only two years worth of crash data.

Crash rates per mile, at one signalized intersection and the midblock are given in Table 40.

Table 64: Overall crash rates on Highway 68

	Before	After
Crashes per mile	127	183
Signalized intersection at Hwy 186 (Per 100 MEV)	0	132
Midblock (Per 100 MVM)	435	507

Crash percentages at all signalized intersections and the midblock are shown in Table 41.

Table 65: Signalized intersection and midblock crash percentage on Highway 68

	Before (%)	After (%)
All signalized intersections	49	49
Midblock	51	51

Crash severity rates and percentages at the midblock are displayed in Table 42.

Table 66: Crash severity rates and percentages on Highway 68 at the midblock

	Per 100 MVM		Percent (%)	
	Before	After	Before	After
Fatalities	0	0	0	0
Broken bones	35	10	8	2
Bruises/abrasions	35	27	8	5
Possible injury	86	117	20	23
PDO	278	353	64	70

Crash severity rates at one intersection are shown in Table 43.

Table 67: Crash severity rates at the intersection of Highways 68 and 173

	Per 100 MEV	
	Before	After
Fatalities	0	0
Broken bones	0	7
Bruises/abrasions	0	16
Possible injury	0	29
PDO	0	79

Crash severity percentages at all intersections are shown in Table 44.

Table 68: Crash severity percentages at all signalized intersections on Highway 68

	Before (%)	After (%)
Fatalities	0	0.2
Broken bones	6	5
Bruises/abrasions	6	10
Possible injury	27	24
PDO	60	61

Collision type crash rates and percentages at the midblock are displayed in Table 45.

Table 69: Collision type crash rate and percent on Highway 68 at the midblock

	Per 100 MVM		Percent (%)	
	before	after	before	after
Rear end	147	260	35	51
Right angle	157	105	38	20
Sideswipe	38	85	9	17
Same direction	29	9	7	2
U-turn	3	4	1	1
Backing	3	9	1	2
Single vehicle	26	28	6	5
Angle	10	11	2	2
Other	3	0	1	0

Collision type crash rates at one intersection are shown in Table 46.

Table 70: Collision type crash rates at the intersection of Highways 68 and 173

	Per 100 MEV	
	Before	After
Rear end	0	30
Right angle	0	90
Sideswipe	0	3
Same direction	0	1
U-turn	0	1
Backing	0	0
Single vehicle	0	1
Angle	0	5
Other	0	1

Collision type crash percentages at all intersections are shown in Table 47.

Table 71: Collision type crash percentages at all signalized intersections of Highway 68

	Before (%)	After (%)
Rear end	39	37
Right angle	50	48
Sideswipe	1	4
Same direction	3	2
U-turn	1	1
Backing	1	0
Single vehicle	2	1
Angle	3	4
Other	0	0

In the overview, the average number of crashes increased by 44% from 127 'before' to 183 'after' (Table 40). This, however, is not adjusted for volume. Midblock crashes increased in rate from 437 to 507 per 100 MVM (Table 40). At the intersection of highways 173 (5400 South) and 68, the crash rate increased from 0 to 132 per 100 MEV (Table 40). The location of crashes did not change, as shown in Table 41.

Now looking at crash severity at the midblock, there were no fatalities before or after construction of the raised median. Also, the rate and percent of crashes resulting in both broken bones and/or bleeding wounds and bruises and abrasions decreased (Table 42). Moreover, property damage only crashes are increasing. The average number of crashes has increased at midblock, but the average number of severe crashes are in decline.

At the intersection of highways 68 and 173, there were no fatalities before or after construction (Table 43). There were also no crashes at all before the raised median was constructed. It is unknown why there were no crashes at this intersection before the raised median was built. After construction, there were 7 crashes resulting in broken bones and/or bleeding wounds per 100 MEV.

Taking a look at the percentage of crashes resulting in differing levels of severity, there is little change between before and after at all signalized intersections in this site. There was one fatality after construction which accounts for 0.2% of all crashes (Table 44).

As to the midblock section, the rear end collisions are increasing and the right angle collisions are decreasing (Table 45). This has been the case in every other highway segment except Highway 186, where rear ends also decreased in rate and percent (see Table 23). Elsewhere, sideswipe and backing collisions are increasing, same direction collisions are decreasing, while all other collisions are staying about the same (Table 45).

Right angle is the most common type of collision at the intersection of highways 68 and 173 (5400 South) after construction. Rear end collisions are the next most common (Table 46). The vast majority of crashes at this intersection are either rear end or right angle.

Looking at all intersections in this segment, the percentage of different collision types did not change much after construction of the raised median. Before construction of the median, 89% of crashes were either rear end or right angle. After construction, 85% of crashes were either rear end or right angle, again (Table 47).

In summary, the number of crashes increased after the raised median was installed. Also, the crash rate at the midblock and the signalized intersection of highways 68 and 173 increased in value. However, the percentage of crashes at signalized intersections versus the midblock stayed the same at 49% and 51%, respectively. Moreover, crashes at the midblock became less severe, while crashes at signalized intersections stayed at about the same level of severity. The reduction in severity at the midblock may be due to the decrease in right angle collisions. Right angle collisions decreased in rate and percent, while rear end collisions, which are less severe, increased in rate and severity. The percentage of individual collision types stayed about the same at signalized intersections.

4.5 Overall Trends

The trends that were consistent throughout all the studied sites after the installation of the raised median are the following:

- Right angle collisions decrease in rate and percentage at the midblock
- Rear end collisions increase in rate and percentage at the midblock
- Crashes do not necessarily shift to the signalized intersection
- Severity of crashes decrease at the midblock and signalized intersections
- Right angle collisions either decrease or stay the same at signalized intersections
- Rear end collisions either increase or stay the same at signalized intersections

4.6 Non-raised median segment comparisons

A comparison of raised median segments with adjacent segments without raised medians was made so that the general trend in crash rates can be compared. If the rates of the non-raised median segments are similar to the raised median segments, then perhaps the raised median was not the cause of any changes in crash rates. Ideally, the other segments will have the same land use, number of lanes, traffic volume, and number of access points. Finding two sites with exactly the same conditions is practically impossible, but these factors were examined in the comparisons.

4.6.1 Highway 68

An adjacent segment of equal length was looked north of the raised median segment. The average crash rates before and after the raised median was installed for both segments are shown in the table below.

Table 72: Comparison of crash rates of segments on Highway 68

	Raised Median	Non-raised Median
Before	820	546
After	1021	682
Percent change	25%	25%

Note: crash rate = crashes per 100 million vehicle miles

Before the raised median was built, the crash rate was 820 and 546 on the raised median and non-raised median segments, respectively. After the raised median was built, the crash rate was 1021 and 682 on the raised median and non-raised median segments, respectively. This translates into a 25% increase in crash rate for both segments. This means that it is likely that an increase in volume had more to do with an increase in traffic crashes than the raised median.

The average annual traffic volume before and after the raised median was built for both segments is shown in the table below.

Table 73: Average annual traffic of segments on Highway 68 before and after raised median installation

	Raised	Non-raised
Before	15,642,842	18,275,550
After	18,101,758	21,368,143
percent change	16%	17%

Both the raised median and non-raised median segments experienced a similar increase in volume as well. It can be concluded that for the raised median segment, the major contributor to an increase in crashes is an increase in volume, rather than the presence of the raised median. This can be concluded due to the similarities in crash rates between the non-raised median segment and raised median segment, with a similar increase in volume.

4.6.2 Highway 186

The crash rates before and after median installation of a western segment of equal length without a raised median was compared to the segment with a raised median. The crash rates are shown in the table below.

Table 74: Comparison of crash rates of segments on Highway 186

	Raised Median	Non-raised median
Before	835	1665
After	749	1143
% Change	-10%	-31%

Note: crash rate = crashes per 100 million vehicle miles

After installation of the raised median, crash rates decreased by 10 and 31 percent on the raised median and non-raised median segment, respectively. There is a large difference in land use between the raised median segment and the non-raised median segment. Light rail train tracks (TRAX) extend along the length of the raised median segment; in fact, the light rail is the raised median. However, most of the non-raised median segment does not have TRAX in the median.

Table 75: Average annual traffic of segments before and after raised median installation on Highway 186

	Raised	Non-raised
Before	12,041,062	8,229,864
After	8,147,242	7,433,955
Percent Change	-32%	-10%

It is interesting that the raised median segment decreased in traffic volume by 32% and the non-raised median segment decreased by 10%, which is a reversal of what occurred with the crash rates. Obviously, drivers are avoiding this route. One possible explanation is land use. For one, the raised median segment is located in a highly commercialized area of downtown Salt Lake City. Secondly, it is adjacent to the University of Utah campus. Lastly, the raised median was constructed as part of a light rail project. This light rail system may make drivers more apprehensive as they drive alongside light rail.

The non-raised median segment located west of the raised median segment is not lined with a light rail system, and there is less volume on the road. This makes this area a little safer to begin with and had a lower volume than the raised median segment before and after installation.

4.6.3 Highway 89: N Temple to 300 North

The segment compared here is on Highway 89 between 300 West and West Temple.

Table 76: Comparison of crash rates of segments on Highway 89 from North Temple to 300 North

	Raised Median	Non-raised median
Before	596	464
After	648	1214
% Change	9%	162%

Note: crash rate = crashes per 100 million vehicle miles

The crash rate on the raised median segment increased only 9% compared to 162% on the non-raised median segment. This may mean that the raised median helped to decrease the crash rates.

Table 77: Average annual traffic of segments on Highway 89 from North Temple to 300 North before and after raised median installation

	Raised	Non-raised
Before	1,518,236	1,518,236
After	1,310,168	1,310,168
Percent Change	-14%	-14%

Unfortunately, the segments are so small that traffic counts are taken at the same location for both segments. Therefore, it will be assumed that the traffic counts are the same for both segments.

Interestingly, the average traffic crashes actually increased for both segments while the average volume decreased. Much of the traffic runs east-west in this vicinity to and from the interstate. The non-raised median segment is an east-west segment, whereas the raised median segment runs north-south. Also, the raised median segment is more of an industrial/residential neighborhood, while the non-raised median segment is a commercialized/tourist area due to the malls and the Salt Lake temple. At any given time during the year, there are out-of-town drivers coming to visit the temple and its vicinity, to see the Christmas lights, or go to a wedding. This draws a large volume of traffic on the non-raised median segment. This may be the reason why the non-raised median section has seen a dramatic increase in crash rate.

4.6.4 Highway 89: 10200 S to 10600 S

The non-raised median segment compared in this part is not adjacent to the raised median segment. The segment is located adjacent to the next Interstate interchange, but it was selected so that similar land uses may exist and because the Jordan Gateway Center is located nearby which may be more comparable to the South Towne Center in regards to land use and traffic patterns. However, it should be realized that access to the Jordan Gateway Center is not on the highway studied.

Table 78: Comparison of crash rates of segments on Highway 89 from 10200 South to 10600 South

	Raised Median	Non-raised Median
Before	463	1914
After	1511	948
% change	228%	-50%

The crash rates increased on the raised median segment by 228% after the raised median installation. However, the segment just north of the raised median segment experienced a 50% reduction in crashes over the same time periods.

The large increase in crash rate on the raised median segment is likely due to the opening of the South Towne Center in 1994, which is the same year the raised median was finished.

Volume was also looked at to see any trends. The average volumes before and after raised median installation are given in Table 55.

Table 79: Average volume of segments on Highway 89 from 10200 South to 10600 South before and after raised median installation

	Raised	Non-raised
Before	3,019,709	2,692,048
After	3,510,320	3,667,645
Percent Change	16%	36%

While the raised median section increased in volume, the non-raised median segment increased even more. It is not clear why the non-raised median segment decreased in crash rate while increasing in volume. Other safety improvements unknown to us might have contributed to this safer condition.

5. CONCLUSIONS

In conclusion, raised medians are recommended where appropriate. Raised medians are useful in decreasing the number of turning conflicts at midblock locations and hence, decrease crash severity. They also control traffic movements, provide pedestrian safety, beautify an area when properly landscaped, and maintain good traffic flow.

However, TWLTLs may be adequate for a highway depending on circumstances described in the literature review section, since they remove left-turning vehicles from through lanes, which improves safety, reduces delay and maintains continuous access to businesses along the highway. TWLTLs are not appropriate in high pedestrian zones, and they tend to attract businesses. Hence, they are probably not good for residential areas or where businesses are not desired.

With regards to the customer survey, about half of customers had to change their driving maneuver when going to a business. Also, one-third of customers felt traffic congestion got worse and that property access declined. On the other hand, more than half believed that traffic safety improved and customer satisfaction did not change for 7 out of 10 customers. With that, 83% said they were just as likely to visit the business. Moreover, accessibility to the store was least important to customers, while product price, product quality and customer service were most important. In all, the raised median may have caused some inconvenience but traffic safety is better and purchasing habits did not change much.

According to the findings of the manager survey, most managers did not perceive a change in the volume of business after the raised median was installed. Also, similar to the customer survey, most managers felt that traffic safety had improved and that traffic congestion had stayed the same. Moreover, managers felt that the most important reason that customers came to their business was because of product price, product quality and customer service, which are things that the manager has some control over.

According to the crash data analysis, six general trends were found. The trends that were consistent throughout all the studied highways are the following:

- Right angle collisions decrease in rate and percentage at the midblock
- Rear end collisions increase in rate and percentage at the midblock
- Crashes do not necessarily shift to the signalized intersection
- Severity of crashes decrease at the midblock and signalized intersections
- Right angle collisions either decrease or stay the same at signalized intersections
- Rear end collisions either increase or stay the same at signalized intersections

Based on these findings, a perocedure for evaluating the need for raised medians was developed. To make it a stand-alone document, the guide is included in Appendix A. Appendix A contains the case of St. George Boulevard in St. George, UT, as an example.

REFERENCES

American Association of State Highway and Transportation officials (AASHTO). *A Policy on Geometric Design of Highways and Streets.* Washington D.C., 2001.

Bonneson, James A. and Patrick T. McCoy. "Median Treatment Selection for Existing Arterial Streets." *ITE Journal*, March 1998, pp. 26-34.

Bonneson, James A. and Patrick T. McCoy. *Capacity and Operational Effects of Midblock Left-Turn Lanes*. NCHRP Report *395*, Transportation Research Board, National Research Council, Washington, D.C., 1997.

Bowman, Brian L. and Vecellio, Robert L. "The Effect of Urban/Suburban Median Types on Both Vehicular and Pedestrian Safety." Paper presented at the 73rd Annual Meeting of the Transportation Research Board, (Preprint CD), January 1994.

BRW Inc. study for Minnesota DOT, August 1998.

California Department of Public Works. *Policy on medians for Conventioal highways in Developed Areas*. Division of Highways Circular Letter #66-108, Department of Public Works, State of California, June 9, 1966.

Center for Transportation Research and Education (CTRE). *Access Management Toolkit: Answers to frequently asked questions*, "Economic Impacts of Access Management," No. 9. http://www.ctre.iastate.edu/research/access/toolkit/9.pdf. Iowa State University, IA. Date of access: July 2003a.

Center for Transportation Research and Education (CTRE). *Access Management Toolkit: Answers to frequently asked questions*, "Access Management and Pedestrian Safety," No. 10. http://www.ctre.iastate.edu/research/access/toolkit/10.pdf. Iowa State University, IA. Date of Access: July 2003b.

Center for Transportation Research and Education (CTRE). *Access Management Toolkit: Answers to frequently Asked Questions*, "Raised Medians at Intersections," No. 17. http://www.ctre.iastate.edu/research/access/toolkit/17.pdf. Iowa State University, IA. Date of Access: July 2003c.

Center for Transportation Research and Education (CTRE). *Access Management Toolkit: Answers to frequently asked questions*, "Continuous Raised Medians," No. 18. http://www.ctre.iastate.edu/research/access/toolkit/18.pdf. Iowa State University, IA. Date of access: July 2003d.

Center for Transportation Research and Education (CTRE). *Access Management Toolkit: Answers to frequently asked questions*, "Incorporating Aesthetics into Access Management," No. 25. http://www.ctre.iastate.edu/research/access/toolkit/25.pdf. Iowa State University, IA. Date of access: July 2004a.

Center for Transportation Research and Education (CTRE). *Iowa Statewide Urban Design Standards Manual*. Iowa State University, Central Iowa Committee, 2004b.

City of Madera, California. http://www.cityofmadera.org/Redevelopment_Agency/programs_and_projects.asp. Date of Access: July 2004.

Dixon, Karen K., John L. Hibbard, and Chris Mroczka. "Public Perception of Median Treatment for Developed Urban Roads." *TRB Circular E-C019: Urban Street Symposium*, June 1999, pp. C-4/1-C-4/13.

Eisele, William L. and William E. Frawley. *A Methodology for Determining Economic Impacts of Raised Medians: Final Project Results*. Report 3904-4. Texas Transportation Institute, The Texas A&M University System, October 2000.

Federal Highway Administration (FHWA). FHWA Course on Bicycle and Pedestrian Transportation: Lesson 16. http://safety.fhwa.dot.gov/pedbike/univcouse/swtoc.htm, Date of Access: June 2003.

Florida Department of Transportation (FDOT). *Median Handbook*. January 1997.

Florida Department of Transportation (FDOT). *Walkable Communities*. State Safety Office, Pedestrian/Bicycle Program, April 1995.

Frawley, William E., and William L. Eisele. *Summary of Access Management Programs and Practices in the United States*. Project Summary Report 1847-S. Texas Transportation Institute, The Texas A&M University System, October 2001.

Glennon, J. C., J. J. Valenta, B. A. Torson, J. A. Azzeh, and C. J. Wilton. *Evaluation of Techniques for the Control of Direct Access to Arterial Highways*. Report No. FHWA-RD-76-85; *Technical Guidelines for the Control of Direct Access to Arterial Highways, Volume 1: General Framework for Implementing Access Control Techniques*. Report No. FHWA-RD-76-86; *Volume II, Detailed Description of Access Control Techniques*. Report No. FHWA-RD-76-87, Federal Highway Administration, August 1975.

Gluck, Jerome, Herbert S. Levinson, and Vergil Stover. *Impacts of Access Management Techniques*. NCHRP Report *420*, Transportation Research Board, National Research Council, Washington, D.C., 1999.

Haguenauer, G. F., J. Upchurch, D. Warren and M. J. Rosenbaum. "Intersections." *Synthesis of Safety Research Related to Traffic Control and Roadway Elements*, Vol. 1, Report FHWA-TS-82-232. Federal Highway Administration, December 1982.

Harwood, Douglass W. and J. C. Glennon. *Selection of Median Treatments for Existing Arterial Highways*. Transportation Research Record 681, Transportation Research Board, 1978.

Harwood, Douglass W. and A. D. St. John. *Passing Lanes and Other Operational Improvements on Two-Lane Highways*. Report FHWA-RD-85/028. FHWA, U. S. Department of Transportation, 1985.

Harwood, Douglass W. "Multilane Design Alternatives for Improving Suburban Highways." NCHRP 282, Transportation Research Board, National Research Council, Washington, D. C., 1986.

Harwood, Douglass W., M. T. Pietrucha, M. D. Wooldridge, R. E. Brydia, and K. Fitzpatrick. *Median Intersection Design*. NCHRP Report *375*, Transportation Research Board, National Research Council, Washington, D.C., 1997.

Hill, Raymond M. "Raised Traffic Channelization." Board of Fire Commissioners, City of Los Angeles, California, April 10, 1967.

Institute of Traffic Engineers (ITE). "Median Treatments." *Traffic Information Progress Series*. Traffic Engineering Council Washington, D.C., http://www.ite.org/pdf/twltl_1.PDF. Date of access: July 2003.

Knoxville Street Master Plan. www.knoxmpc.org/ plans/treeplan/3short.htm. Date of Access: July 2004.

Long, G. D., C. T. Gan and B. S. Morrison. *Safety Impacts of Selected Median and Access Design Features.* Report to the Florida Department of Transportation, Transportation Research Center, University of Florida, May 28, 1993.

Los Angeles Evening Outlook. "Fire Department Against Wilshire Planters," Wednesday, January 31, 1962.

Missouri Department of Transportation (MoDOT). *Access Management Guidelines.* Jefferson City, MO, September 2003.

Mukherjee, Dibyendu, Arun Chatterjee, and Richard Margiotta. "Choosing Between a Median and a TWLTL for Suburban Arterials." *ITE Journal*, July 1993, pp. 25-30.

National Highway Institute (NHI). *Access Management, Location and Design: Participant Notebook*. NHI Course No. 15255. U. S. Department of Transportation. Federal Highway Administration. Washington, D. C., February 1992.

O'Shea, Jillyn K., Thomas W. Rioux, and Randy B. Machemehl. *Design of Medians for Principal Arterials*. Project Summary Report 0-1846-S. Center for Transportation Research, Bureau of Engineering Research, The University of Texas at Austin, August 2001.

Parker, Martin R. *Methodology for Selecting Urban Median Treatments: A User's Manual*. Charlottesville, VA: Virginia Highway and Transportation Research Council, 1981.

Parker, Martin R. *Design Guidelines for Raised and Traversable Medians in Urban Areas*. Virginia Highway and Transportation Research Council, Virginia Department of Transportation, December 1983.

Parsonson, Peter S. *Development of Policies and Guidelines Governing Median Selection*. Final Report, prepared for Gwinnett County, Georgia, School of Civil Engineering, Georgia Institute of Technology, Atlanta, GA, February 1990.

Parsonson, Peter S., Waters, M. and Fincher, J. S. "Effect on Safety of Replacing An Arterial Two-Way Left-Turn Lane with a Raised Median." Published in the *Proceedings* of the First National Access Management Conference, Vail, Colorado, 1993.

Reish, Robert, and Nazir Lalani. "Why Not a Raised Median?" *ITE Journal*, August 1987, pp. 31-34.

Squires, Christopher A., and Peter S. Parsonson. "Crash Comparison of Raised Median and Two-Way Left-Turn Lane and Median Treatments." *Transportation Research Record 1239*. Transportation Research Board, National Research Council, Washington, D.C., 1989, pp. 30-40.

Stover, Vergil, Samuel Tignor and Merton Rosenbaum. *Synthesis of Safety Research Related to Traffic Control and Roadway Elements: Volume 1*. Office of research, Development and Technology, Federal Highway Administration, US Department of Transportation, December 1982.

Transportation Research Board. *Access Management Manual*, Washington, D. C., 2003.

Transportation Research Board. *Highway Capacity Manual*, Washington, D. C., 1997.

Transportation Research Institute. *Medians: A Survey of the Literature*. Background Paper No. 4 prepared for the Oregon Department of Transportation, Salem, OR. Oregon State University, Revised 1997.

Van Winkle, Stephen N. "Raised Medians vs. Flush Medians." *ITE Journal*, April 1988, pp. 25-26.

APPENDIX A: A GUIDE FOR EVALUATING THE NEED FOR RAISED MEDIANS

A.1 Factors and Criteria

Reasons for considering a raised median for an arterial vary. Some are to reduce severe crashes caused by lack of control, to provide room for light rail, to provide better channelization of traffic, or even to beautify a neighborhood. It is often difficult to decide when the appropriate time for installing a raised median would be because they typically serve very specific purposes. The guide discussed herein consists of comparing the conditions of the site with seven criteria. The criteria given here are general suggestions for determining when to install raised medians. The UDOT engineers are encouraged to check these factors when they make a decision of selecting the type of median.

Factors	Criteria
Crashes	If there are a high number of crashes that could be prevented with a raised median on a 4 or 6 lane roadway, then installing a raised median should be considered.
Pedestrians	If there are a high number of pedestrian crossings in the mid-block or at an intersection, a raised median should be provided on a four-plus lane road.
Volume	If the volume exceeds AADT 24000 to 28000 on a principal arterial or minor arterial in urban areas, a raised median installation should be considered.
Delay	If there is excessive delay on an undivided roadway because of left-turns, then install a TWLTL or a raised median. If a TWLTL does not accommodate all the left-turning vehicles and causes backing up and delay, then install a raised median and route the traffic to an intersection where the traffic can be better accommodated.
Driveways per mile	If there are more than 60 driveways per mile, consider installing a raised median.
Mid-block opening	Mid-block openings can be considered if the distance constraints are met and the opening would help alleviate strain on nearby intersections when a large generator is present.
Number of lanes	A raised median should be given consideration when the number of through lanes is more than four and the number of driveways per mile is high.

The subsequent sections provide rationales for setting up these criteria.

Crashes: ***If there are a high number of crashes that could be prevented with a raised median on a 4 or 6 lane roadway, then installing a raised median should be considered.***

The majority of crashes that can be eliminated by raised medians are crossing crashes. Figures A-1 and A-2 show the reduction in conflict points when raised medians are introduced. When there are high crash rates, a raised median is preferred over Two-Way Left-Turn Lanes (TWLTLs), and TWLTLs are preferred over undivided roadways.

Many studies have indicated a decrease in crashes. A before-and-after crash study (Chapter 4) conducted on four highways in Utah that received raised median treatments in the past few years indicated that crash severity decreased, right angle crashes decreased at the midblock, rear end collisions increased at the midblock. Also, at signalized intersections, right angle crashes either decrease or stay the same and rear end crashes either increase or stay the same. Furthermore, it was found that crashes do not necessarily shift to the signalized intersection.

It should be recognized though that TWLTLs may be adequate in some situations, if the original cross-section is undivided. Also note that there may be a conflict between vehicles and the raised median depending on the design features that could make a raised median inappropriate. Furthermore, it is not well understood whether raised medians cause an increase in crashes on parallel routes. Therefore, the engineer needs to carefully analyze the corridor as a system. Raised medians have been associated with less right angle, sideswipe and head-on collisions (Gluck, Levinson, and Stover 1999); however, the before and after study conducted in Utah (Chapter 4) does not give a solid trend regarding sideswipe and head-on collisions. It does show that right angle collisions decrease at the midblock and may decrease at the intersection or stay the same.

For installing a raised median, access to the businesses along the roadway is an issue. Most driveway related crashes are left-turning crashes as shown in Figure A-4. A raised median could remove that conflict because unrestricted left-turns will not be available with a raised median.

Here the findings of several studies on the safety of raised medians are presented to further assist the engineer to understand the effect of installing a raised median for safety reasons. According to Squires and Parsonson (1989) in Georgia, for every 100 crashes on a TWLTL road, there were 85 and 79 divided highway crashes, on 4- and 6-lane roadways, respectively. In Michigan, there were 43 and 51 divided highway crashes on 4- and 6-lane roadways, respectively. In Florida, there were 75 and 75 divided highway crashes on 4- and 6-lane roadways, respectively. These values are summarized in Table A-1. Because contributing causes for crashes may not be simply one type of median, the statistics vary from state to state. For example, divided highways in Michigan have half as many crashes, but in Florida there are only 25% less crashes on divided highways. Even so, there seems to be in general a reduction in crashes with divided highways over TWLTLs.

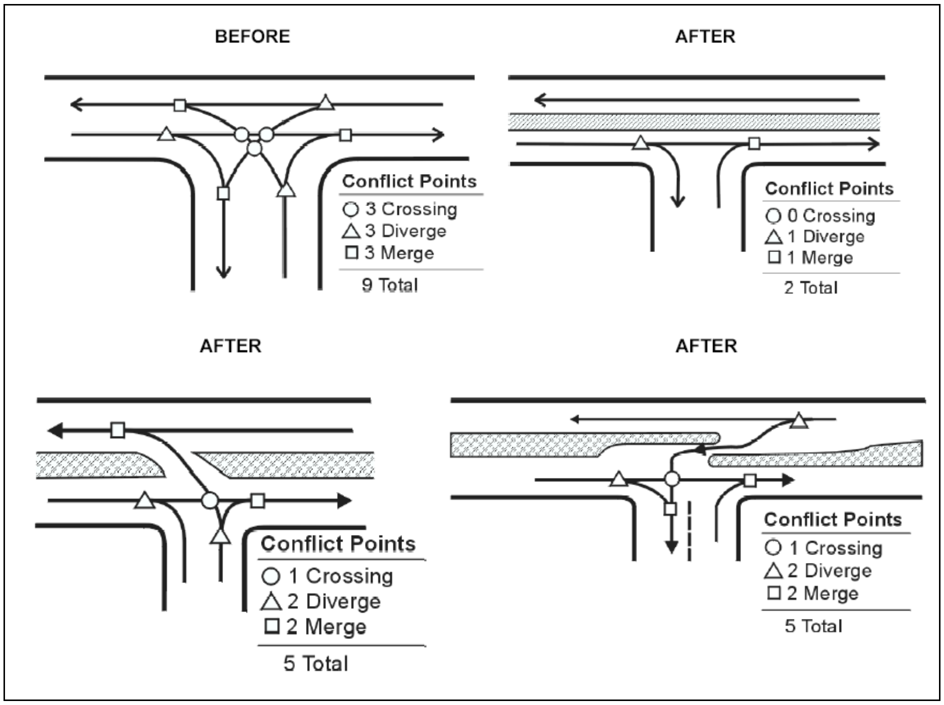

Figure A-1: Before and after conflict points on a 3-leg intersection show benefits of raised medians
(Source: CTRE 2004b)

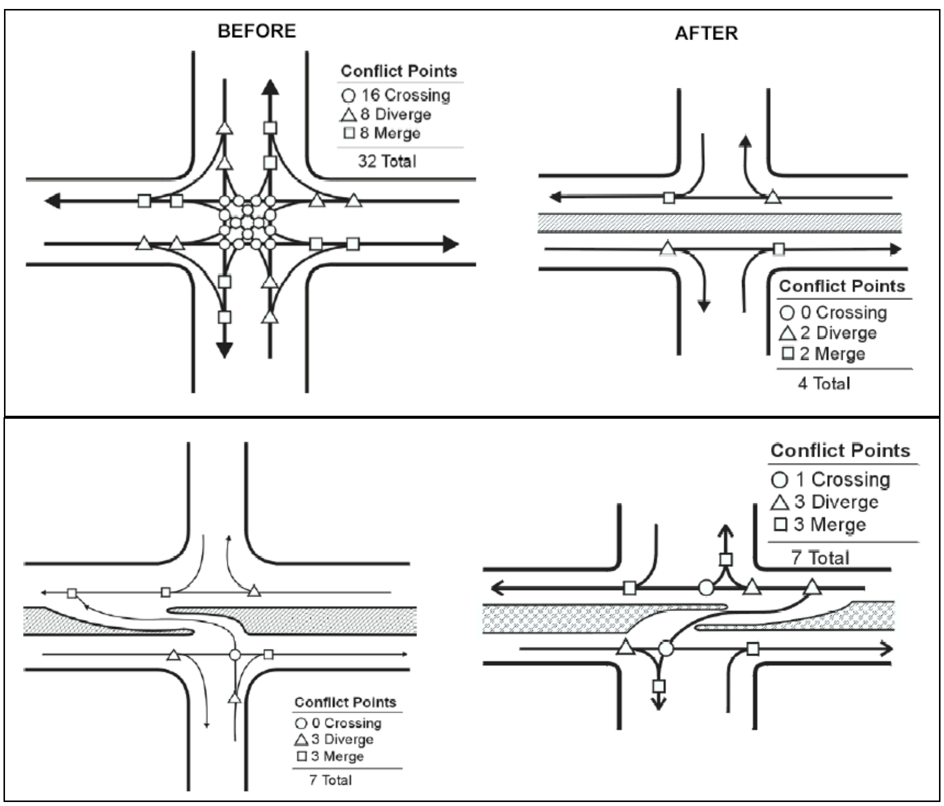

Figure A-2: Conflict points on a 4-leg intersection
(Source: CTRE 2004b)

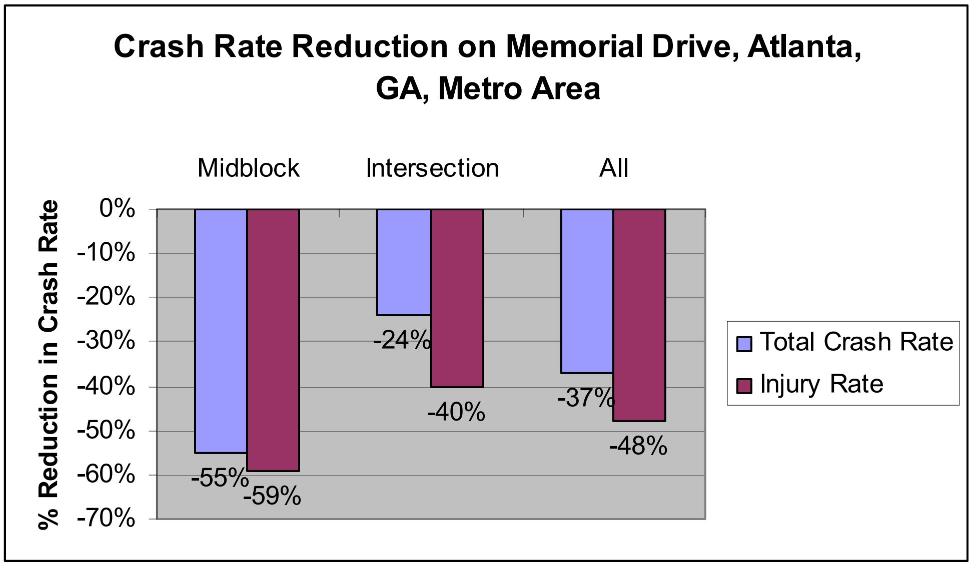

Figure A-3: Crash rate reductions on Memorial Drive
(Source: Parsonson, Waters and Fincher, 1993)

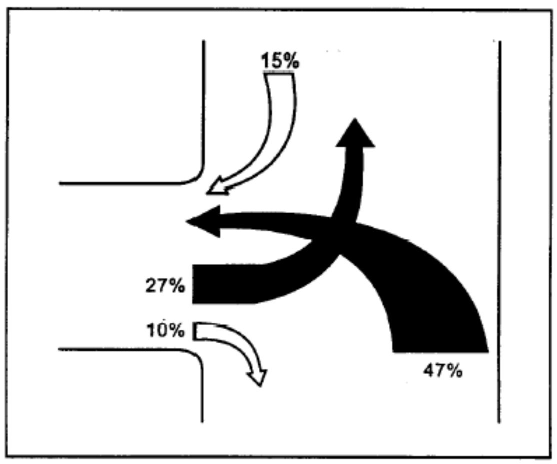

Figure A-4: Percentage of driveway crashes by movement
(Source: NHI 1992)

Table A-1: Percentage of divided highway crash rates as compared to highways with TWLTL

Divided highway crash rates as a percentage of TWLTL highway crash rates		
State	4-lane	6-lane
Georgia	85%	79%
Michigan	43%	51%
Florida	75%	75%

(Source: Squires and Parsonson 1989)

A study done in Minnesota (BRW 1998) shows that the crash rate of an urban 4-lane roadway with raised median is similar to a 5-lane roadway with TWLTL (see Table A-2). It is important to note from the table that a 4-lane undivided highway has a higher crash rate than a raised median or TWLTL treatment. The table also indicates that a raised median is as effective at reducing crashes as a TWLTL.

Table A-2: Crash rate per million vehicle miles versus roadway type on urban arterials

Roadway Type	Crash Rate
4-lane undivided	6.75
3-lane TWLTL	4.96
4-lane with raised median	4.02
5-lane with TWLTL	4.01

(Source: BRW 1998)

The Center for Transportation Research and Education (CTRE) has indicated several advantages of raised medians in terms of safety (CTRE 2003b,d). They prevent crashes caused by crossover traffic, reduce headlight glare, and provide pedestrian protection. Raised medians should be used when safety is a concern; however, TWLTLs may be adequate if there are only 4 through lanes. Otherwise, crash rates increase dramatically.

In Table A-3, Haguenauer et al. (1982) studied crash rates at unsignalized and signalized intersections and also whether there was a signal or not. They found that there tend to be fewer crashes when there is a left-turn lane. Also, there is a larger difference in crash rates for the unsignalized intersection.

Table A-3: Effect of left-turn bays on crash rates

Effect of left-turn bays on crash rates				
	Crash rates (per million entering vehicles)			
	unsignalized		Signalized	
Type of crash	No left-turn lane	Left-turn lane	No left-turn lane	Left-turn lane
left turns	1.2	0.12	0.65	0.37
all other	3.15*	0.92*	1.82*	1.17
Total	4.35*	1.04*	2.47*	1.54*

* indicates statistically significant difference
(Source: Haguenauer et al. 1982)

Similarly in Tables A-4 and A-5, there is a larger percent change for unsignalized intersections than for signalized intersections when before and after crash rates are compared. These tables do not relate directly to raised medians but they have implications for TWLTLs and raised medians with left-turn bays.

Also, left-turn crashes tend to be the most severe because they are crossing lanes of traffic. A raised median at a three-leg (T) (Figure A-1) or four-leg intersection (Figure A-2), will either not allow left-turns or restrict left-turns to one direction, making them a bit safer. The strictest scenario on the top-right of both figures A-1 and A-2 do not allow left-turns, while the other two raised median scenarios on bottom allow only one left-turn, which results in only one crossing conflict point from a left-turn. Without a raised median (top-left), there are 9 conflict points at a T-intersection and 32 conflict points at a four-leg intersection. The presence of a raised median at a T-intersection will simplify turning maneuvers to a great extent.

Table A-4: Crash rates before and after construction of left-turn bays for signalized and unsignalized intersections

Crash Rates Before and After Construction of Left-Turn Bays (per million entering vehicles)						
	Signalized			Unsignalized		
Light Conditions	Rate Before	Rate After	Percent Change	Rate Before	Rate After	Percent Change
Day	0.94	0.73	-22	1.12	0.5	-55
Night	1.12	1	-11	1.24	0.73	-41
Total	1	0.82	-18	1.16	0.58	-50

(Source: Hagenauer et al 1982)

Table A-5: Crash rates after construction of left-turn bays

Crash Rates After Construction of Left-Turn Bays (per million entering vehicles)						
	Signalized			Unsignalized		
Severity	Before Rate	After Rate	Percent Change	Before Rate	After Rate	Percent Change
Property Damage	0.62	0.48	-23	0.67	0.37	-45
Injury	0.37	0.34	-8	0.47	0.2	-57
Fatal	0	0.01	-	0.02	0.01	-50

(Haguenauer et al 1982)

Bowman and Vecellio (1994) studied the difference in crash rates involving personal injury between raised medians and TWLTLs in CBDs and suburban areas and reported a significant difference in personal injury related vehicular crash rates as shown in Tables A-6 and A-7. Table A-6 shows crash rates of five crash types of raised medians and TWLTLs at the midblock, while Table A-7 shows frequency, crash rate and crash percentage of raised medians and TWLTLs for PDO, injury and fatal crashes.

Table A-6 shows rear-end, right angle, head-on, left-turn, and other crash rates per 100 MVM of raised medians to be less than corresponding crash rates of TWLTLs. Table A-7 shows PDO, injury and fatal crash rates of raised medians are lower than corresponding crash rates of TWLTLs.

Figure A-5 shows injury and PDO crash rates on undivided, TWLTL, flush paved, and raised median treatments of 4-lane urban arterials in Florida. Table A-8 compares mean crash rates of three median types on suburban arterials.

In Figure A-5, undivided roadways exhibit the largest crash rate per MVM for both injury and PDO crashes. Raised medians exhibit the lowest crash rate for both injury and PDO crashes. In Table A-8, raised medians had the lowest mean crash rates and TWLTLs had the highest mean crash rates on suburban arterials.

Table A-6: Midblock crash rates by median type and crash type

Summary of Suburban Midblock Vehicular Crash Rates by Crash Type (per 100 million VMT)		
Crash Type	*Raised*	*TWLTL*
Rear-End	80.98	139.61
Right Angle	35.05	63.26
Head-On	1.34	2.55
Left-Turn	24.35	52.5
Other	47.52	53.45

(Source: Bowman and Vecellio 1994)

Table A-7: Suburban vehicle crash rate by severity and median type

Summary of Suburban Vehicle Crash Rate Severity by Median Type (per 100 million VMT)			
Severity	**Variable**	**Raised**	**TWLTL**
PDO	frequency	2649	4855
	crash rate	131.12	221.43
	% crashes	69.3	71.1
Injury	frequency	1169	1962
	crash rate	57.86	89.48
	% crashes	30.6	28.7
Fatal	frequency	5	10
	crash rate	0.25	0.46
	% crashes	0.1	0.2

(Source: Bowman and Vecellio 1994)

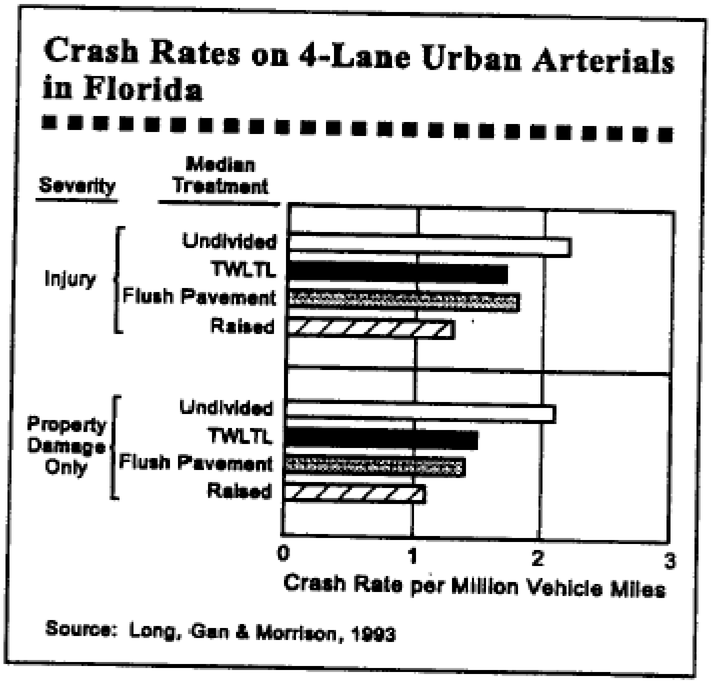

Figure A-5: Percentage of driveway crashes by movement
(Source: Bowman and Vecellio 1994)

Table A-8: Comparison of vehicular crash rates on suburban arterials

Comparison	mean crash rates	significant difference*
Raised median v TWLTL	373 vs. 676	yes
Raised median v Undivided	373 vs. 409	yes
TWLTL v Undivided	676 vs. 409	no

Notes: *95% confidence level, Scheffe multiple comparison test
(Source: Bowman and Vecellio 1994)

Pedestrians: ***If there are a high number of pedestrian crossings in the mid-block or at an intersection, a raised median should be provided on a four-plus lane road.***

Long, Gan, and Morrison (1993) reported that non-traversable medians are associated with less pedestrian crash rates per 100 million vehicle miles as compared to TWLTLs and undivided roadways in urban areas as shown in Figure A-6.

In a similar pedestrian related study, Oregon State University reported that mid-block pedestrian crash rates were found to be almost twice as much for undivided 4-lane roadways and 5-lane-with-TWLTL roadways than for divided 4-lane roadways as shown in Table A-9 (CTRE 2003b). The table also shows that at intersections, there are about 2.5 times more pedestrian crashes for undivided 4-lane roadways and 5-lane with TWLTL roadways than for divided 4-lane roadways.

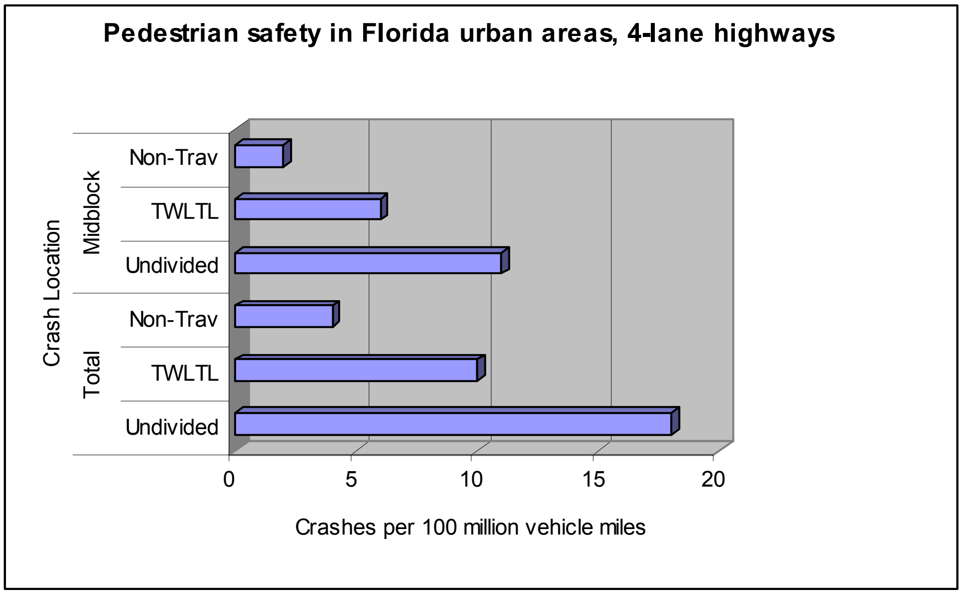

Figure A-6: Pedestrian crash rates in Florida urban areas
(Source: Harwood and Glennon 1978)

Table A-9: Pedestrian crash rates versus roadway type

Roadway Type	Median	Mid-block pedestrian crash rate	Intersection pedestrian crash rate
Undivided 4 lane	None	6.69	2.32
5 lane (TWLTL)	Painted	6.66	2.49
Divided 4 lane	Raised	3.86	0.97

(Source: Bowman and Vecellio 1994)

In another pedestrian related study Bowman and Vecellio (1994) indicated that pedestrian crashes were twice as common on TWLTLs than on raised medians in CBDs (Bonneson and McCoy 1997).

The reason for a lower mid-block and intersection pedestrian crash rates for divided 4-lane roadways may be because the divider, or raised median, allows pedestrians to cross the road in two segments rather than one. Figure A-7 shows that when there is a raised median, pedestrians can cross the street in two segments rather one. When there is not a raised median, pedestrians have to look both ways before crossing, as in Figure A-8.

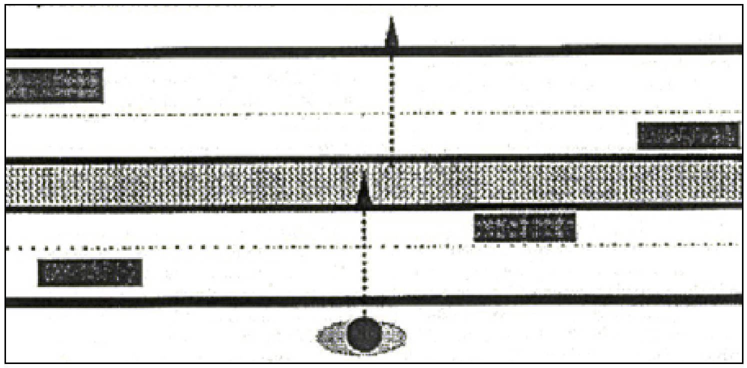

Figure A-7: Crossing maneuver for pedestrians with a raised median
(Source: FHWA 2003)

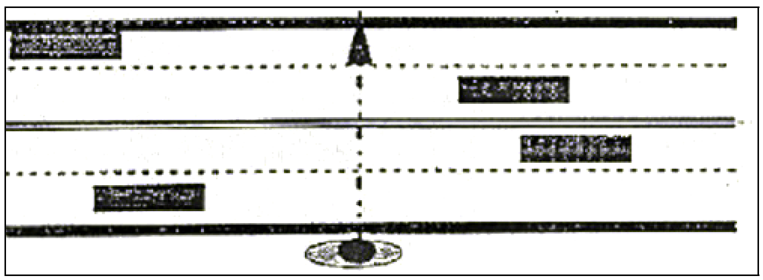

Figure A-8: Crossing maneuver for pedestrians without a raised median
(Source: FHWA 2003)

Two advantages for pedestrians when a raised median is present are:

- Pedestrians have less distance to travel before reaching a safe zone.
- Pedestrians only have to look in one direction before crossing to a safe zone.

If the pedestrian is crossing a road without a raised median, four lanes of traffic must be crossed which requires a 12-second gap at 4 fps. However, if the pedestrian is crossing a road with a raised median, two lanes of traffic must be crossed which only requires a 6 second gap. A raised median also simplifies the crossing maneuver by allowing the pedestrian to look just one direction before crossing, then wait, and look the other direction before crossing again as shown in Figure A-7. However, the raised median must be at least 4 feet in width in order for pedestrians to be safe. They also need to be clearly visible at day and night. In addition, non-mountable medians are better for pedestrian safety because out-of-control vehicles may be stopped by a 12-inch curb.

Table A-10, taken from Bowman and Vecellio (1994) shows that there are almost twice as many pedestrian crashes on arterials with TWLTLs than on arterials with a raised median or no median. This may be due to the extra lane on an arterial with a TWLTL. There are three disadvantages of a road with a TWLTL: There is an extra lane to cross, there is no refuge, and pedestrians must look in both directions before attempting to cross. A TWLTL arterial with 5 lanes takes one 15 second gap to cross the arterial after looking both ways, instead of 12 for an undivided road and 6 for a road with a raised median.

Bowmand and Vocellio (1994) reported that some pedestrians may use the TWLTL as a refuge. Five percent of pedestrians used a TWLTL as a refuge versus 18% on a raised median. Clearly, pedestrians feel safer using a raised median as a refuge than a TWLTL. This is especially important for the elderly because their walking speeds are significantly lower than typical middle-aged pedestrians. Most agencies believe that 6 feet to 16 feet raised median width is suitable for pedestrian refuge.

Table A-10: Comparison of median type pedestrian-vehicle crash rates at mid-block in CBDs

Comparison	Mean Crash Rates (per 100 million VMT)
Raised v TWLTL	19.1 v 41.1
Raised v Undivided	19.2 v 87.3
TWLTL v Undivided	41.1 v 87.3

(Source: Bowman and Vocellio 1994)

Volume: ***If the volume exceeds AADT 24000 to 28000 on a principal arterial or minor arterial in urban areas, a raised median installation should be considered.***

Gluck, Levinson and Stover (1999) found traffic volume to be a predictor of crashes as shown in Figure A-9. When the ADT is about 10,000, the differences in crashes per mile is negligible between the three cross sections (undivided, TWLTL, and raised median). However, as the ADT increases the number of crashes per mile increases much more for the undivided cross section than for either the TWLTL or raised median cross sections.

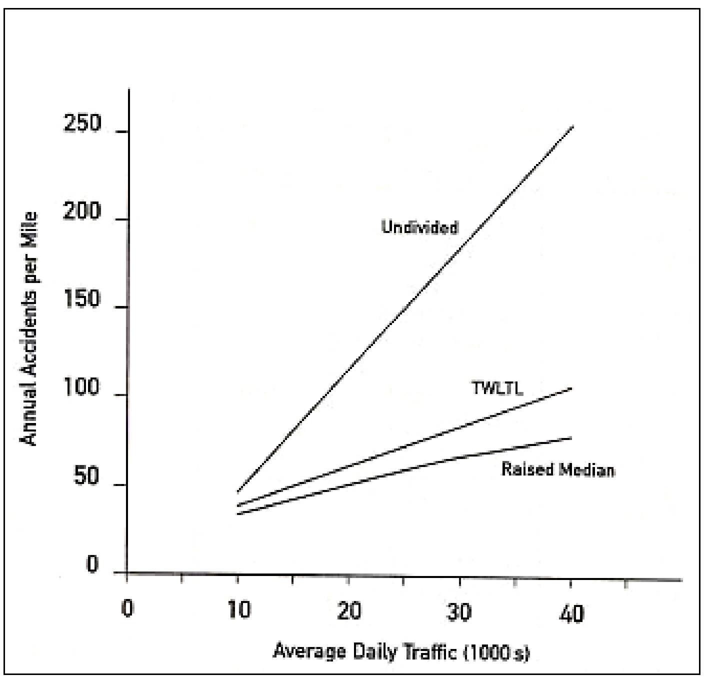

Figure A-9: ADT versus annual crashes per mile
(Source: Gluck, Levinson and Stover 1999)

Squires and Parsonson (1989) reported that in urban areas, raised medians are safer at an ADT of 30,000 or more unless there are seven or more driveways per mile and/or two or more signals per mile. Also, TWLTLs are safer at an ADT of 10,000 unless the driveways per mile are low. This is because Squires and Parsonson found that when there are few driveways that attract lots of traffic, raised medians are safer, but when there are many driveways that attract relatively little traffic, TWLTLs are safer. This finding is supported by Parker (1983) and Harwood and St. John (1985). It is contrary to the findings of Azzeh et al. (1975). Furthermore, with higher volumes of opposing traffic, raised medians provide concentrated areas to make left-turns which are safer than larger maneuver areas, such as found on TWLTLs.

Delay: ***If there is excessive delay on an undivided roadway because of left-turns, then install a TWLTL or a raised median. If a TWLTL does not accommodate all the left-turning vehicles and causes backing up and delay, then install a raised median and route the traffic to an intersection where the traffic can be better accommodated.***

Excessive delay is typically caused by left-turn vehicles on through lanes of undivided roadways. A TWLTL may be adequate for this type of delay. However, if a TWLTL does not provide an appropriate and safe turning maneuver, traffic may need to be rerouted with a raised median.

Figure A-10 was taken from Bonneson and McCoy (1998) and shows that delay for raised medians and TWLTLs are very similar when there are 4 through lanes, 10% left-turns per quarter mile and 60 access points per mile.

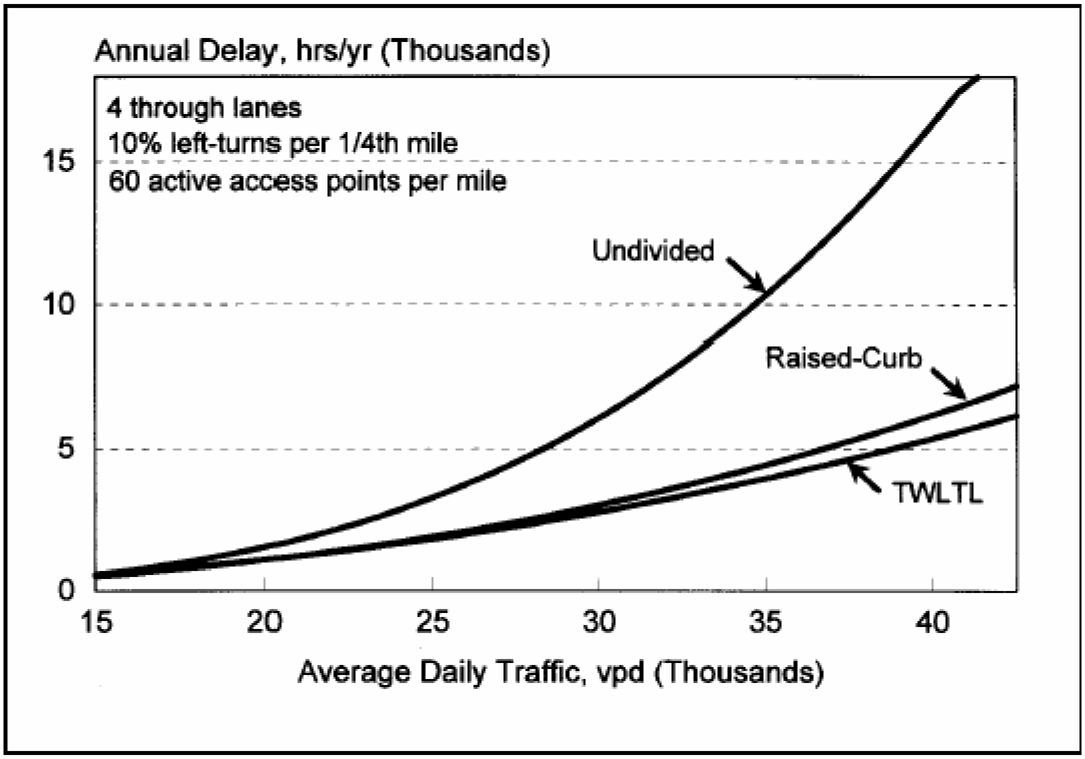

Figure A-10: Average annual delay to major-street left-turn and through vehicles
(Source: Bonneson and McCoy 1998)

Driveways per mile: *If there are more than 60 driveways per mile, consider installing a raised median.*

Table A-11 shows that there is an associated increase in crashes as the number of driveways per mile increases. For example, there is a 74 % increase in crashes when there are 20 to 40 driveways per mile compared to less than 20 driveways per mile.

Table A-11: Crash rate versus driveways per mile for an undivided multilane highway

Driveways per mile	Approximate driveways per 500 feet	Representative crash rate	Increase in crashes
Under 20	Under 2	3.4	--
20 to 40	2 to 4	5.9	+74%
40 to 60	4 to 6	7.4	+118%
Over 60	Over 6	9.2	+171%

(Source: Gluck, Levinson, and Stover 1999)

Table A-12 below presents crash rates by median treatment as predicted by signalized access density. The signalized access density is divided into 4 categories. As the signalized access density increases, the overall crash rate increases. The undivided arterials experience the highest crash rates followed by the TWLTL arterials, and the non-traversable arterials have the lowest crash rates.

Table A-12: Crash rates by signalized access density and median treatment in urban and suburban areas per million VMT

Signalized Access Density (access points per mile)	Undivided	TWLTL	Raised Median	Total
<=2	4.01	4.13	2.75	3.53
2.01-4	8.2	7.02	5.66	6.89
4.01-6	9.87	7.42	5.99	7.49
>6	9.45	9.13	8.26	9.11
Total	8.59	6.88	5.19	

(Source: Gluck, Levinson, and Stover 1999)

Table A-13 below shows the crash rates of median treatments as predicted by access density, which includes unsignalized and signalized access points. The overall crash rates increase with increased access density. Also, the undivided arterials experience the highest crash rates, followed by TWLTL arterials, and the raised median arterials experience the least crash rates.

Table A-13: Crash rates by access density and median treatment in urban and suburban areas per million VMT

Access Density*	Undivided	TWLTL	Raised Median	Total
<=20	3.82	--	2.94	3.24
20.01-40	8.27	5.87	5.13	5.9
40.01-60	9.35	7.43	6.47	7.37
>60	9.55	9.17	5.4	8.59
Total	8.59	6.88	5.19	

* Access density includes unsignalized and signalized access points per mile
(Source: Gluck, Levinson and Stover 1999)

Table A-14 shows the amount of crashes per mile that will be reduced for two scenarios. The first scenario has low roadside development (< 30 driveways per mile) and low ADT (< 5,000). The second scenario has high roadside development (> 60 driveways per mile) and high ADT (> 15,000). In the first scenario, the reduction in crashes per mile is much greater with the raised median, which suggests that TWLTLs are not as effective in low density areas. In the second scenario, the reduction in crashes per mile is about the same for raised medians and TWLTLs. This seems to suggest that raised medians and TWLTLs are effective at reducing crashes per mile in high density areas.

Table A-14: Estimated annual reduction in crashes per mile based on roadside development and ADT

Conditions		Estimated annual reduction in crashes per mile	
Level of roadside development	Highway ADT	Raised Median	TWLTL
Low, < 30 driveways per mile	Low, <5,000	22	4.4
High, >60 driveways per mile	High, >15,000	31.2	28.1

(Source: Glennon et al. 1975)

It should be noted, though, that Squires and Parsonson (1989) reported that TWLTLs should be used instead of raised medians when the number of driveways per mile exceeds 45. Harwood and St. John (1985) also reported this finding in an FHWA report.

In summary, Squire and Parsonson (1989) concluded when high-volume driveways are present, raised medians would be safer, and when a large number of low-volume driveways are present, TWLTLs would be safer. Squires and Parsonson's findings are supported by Parker (1983) and Harwood and St. John (1985). However, this finding is contrary to the finding of Glennon et al. (1975) in their FHWA report.

Mid-block Openings: ***Mid-block openings can be considered if the distance constraints are met and the opening would help alleviate strain on nearby intersections when a large generator is present.***

Table A-15, taken from the MoDOT's minimum guidelines (2002), is a general guide for installation of mid-block openings in urban areas. The guidelines in this table are similar but may vary slightly from other guidelines, but in general they are basically the same.

Table A-15: MoDOT minimum lengths between mid-block openings

Roadway Classification	In Current and Projected Urban Areas
Major Arterial	1320 to 2640 ft (full); 660 to 1320 ft (directional)
Minor Arterial	1320 ft (full); 660 ft (directional)

(Source: MoDOT 2003)

The preferred type of median treatment depends on certain factors as found in NCHRP Report 395 (Bonneson and McCoy 1997) which is shown in Table A-16.

Table A-16 Preferred mid-block left-turn treatment for different factors

Comparison Factor	Preferred Mid-block Left-turn treatment		
	Raised Median vs TWLTL	Raised Median vs Undivided	TWLTL vs Undivided
Operational Effects			
Major street through movement delay	nd	Raised Median	TWLTL
Major street left-turn movement delay	nd	Raised Median	TWLTL
Minor-street left & through delay	nd	Raised Median	TWLTL
Pedestrian refuge area	Raised Median	Raised Median	nd
Operational Flexibility	TWLTL	Undivided	nd
Other Effects			
cost of maintaining delineation	nd	Undivided	Undivided
Median reconstruction cost	TWLTL	Undivided	Undivided
Facilitate snow removal	TWLTL	Undivided	nd
Visibility of delineation	Raised Median	Raised Median	nd
Aesthetic potential	Raised Median	Raised Median	nd
Location for signs and signal poles	Raised Median	Raised Median	nd

(Source: Bonneson and McCoy 1997)

Number of lanes: ***A raised median should be given consideration when the number of through lanes is more than four and the number of driveways per mile is high.***

Several southwestern states found that the crash rate on a 6 through lane road with a TWLTL is as high as 11 crashes per 100 MVM. This crash rate is similar to an undivided road with many access points per mile. The crashes occur because there are just too many lanes for drivers to cross (CTRE 2003a).

A.2 Sample Application of the Guide – St. George Boulevard, St. George, UT

Saint George Boulevard in Saint George, Utah is 2 miles long and runs east-west while intersecting Interstate 15 near the east end and stopping at Bluff Drive, a principal arterial, on the west end (see Figure A-11). Currently, there is no parallel parking permitted, and no shoulder available, and the speed limit is 30 miles per hour. The boulevard has 5 lanes including a TWLTL in the middle. There are 111 driveways and 15 intersections, which equates to 56 driveways per mile and 8 intersections per mile. The businesses along the boulevard are mostly auto-oriented, gas stations, motels and inns, beauty salons, lunch diners and real estate agencies. On the north side of the boulevard, from 4th East to 7th East there are high cliffs that cut off parallel streets. Rear-end and intersection accidents are the most common. Site circulation at the businesses is poor, and the road cannot be widened unless businesses are set back. There is a division between those who oppose and those who are for raised medians among the businesses on the corridor.

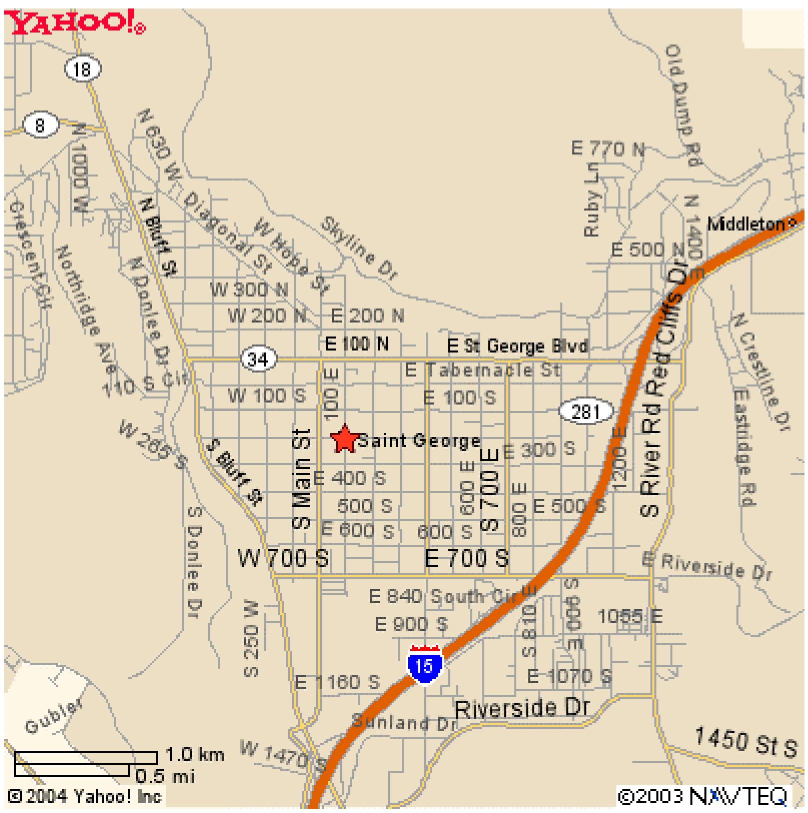

Figure A-11: Saint George Boulevard
(Source: maps.yahoo.com)

As an example, the guide developed in this study is used to evaluate whether Saint George Boulevard should receive a raised median. The follow-up report will discuss what Saint George actually did and the reasons that they did them, in order to compare the reasons for installing a raised median.

The decision making process is based on these factors discussed in Appendix A-1:

- Accidents
- Pedestrians
- Volume
- Delay
- Driveways per mile
- Midblock opening
- Number of lanes

Accidents

The most accidents at an intersection take place at 1000 East, Bluff Street, River Road, Northbound on-ramp to Interstate 15, and Southbound on-ramp, in that order (see Table A-17). Saint George Boulevard extends from Bluff Road on the west to River Road on the east. 1000 East is the first road west of the interstate, and the interstate is adjacent to River Road.

The two highest collision types between 1992 and 2002 are rear end (60%) and right angle (24%). About 39% of all rear end accidents occur at an intersection. About 52% of all right angle accidents between 1992 and 2002 occur at a traffic signal. This leaves 48% that occur at the midblock.

The reason that most accidents occur at 1000 East is because of the short length between the off-ramp of the interstate and 1000 East. This creates problems with merging and diverging, as there are two through lanes, a right turn lane and a left-turn lane. So, cars traveling west have to compete with cars getting off of the interstate. For this reason there is no wonder the two highest accident segments are 1000 East – SB Off-Ramp and 900 East – 1000 East (see Table A-18). The third, fourth and fifth highest segments are 700 East -800 East, Bluff Street – 400 West and 400 West – 300 West.

It is not really clear why 700 East - 800 East has a lot of accidents except that it is still close to the interstate, and there is a gas station and a McDonald's on opposite sides of the street. Bluff Road is the other major North-South thoroughfare in St. George besides the interstate, and it carries about 40,000 ADT in that area.

Table A-17: Highest ranking accident intersections on St. George Blvd

Intersection	2003	2002	2001	Total	Rank
1000 East	16	31	26	73	1
Bluff Street	7	28	29	64	2
River Road	14	25	24	63	3
NB On-Ramp	13	12	18	43	4
SB Off-Ramp	8	17	11	36	5

2003 includes 1/1/03 – 6/30/03 only
(Source: St. George Traffic Engineering Division)

Table A-18: Higest ranking accident segments on St. George Blvd

Segment	2003	2002	2001	Total	Rank
1000 East - SB Off-Ramp	11	27	9	47	1
900 East - 1000 East	7	13	14	34	2
700 East - 800 East	8	13	5	26	3
Bluff Street - 400 West	4	12	8	24	4
400 West - 300 West	7	7	8	22	5

2003 inlcudes 1/1/03 – 6/30/03 only
(Source: St. George Traffic Engineering Division)

Knowing where the high accident areas are, the question is: Will a raised median help reduce the types of accidents that prevail on this boulevard? Raised medians typically reduce right angle accidents between left-turn (LT) vehicles and on-coming through vehicles as well as the severity of accidents. They also tend to cause accidents to shift to the intersections. In the accident study done in Chapter 4, these were the trends for other raised median roads. They also tend to increase rear-end, sideswipe and merging/diverging accidents.

Based on the knowledge that there are already high accident rates at the intersections, a raised median may not improve these areas. However, potential for right angle accidents on the midblock will be non-existent.

Pedestrians

This boulevard is not pedestrian friendly because of high traffic volume, narrow sidewalks, mostly auto-oriented businesses, fast-food chains, and not many attractive locations for pedestrians to stroll, especially on the east side of the boulevard. Therefore, a raised median would do little benefit for the small amount of pedestrians.

On the other hand, there is an antique mall near Main Street on this road that is very attractive and friendly to pedestrians. It has many small shops and attractive restaurants. Given that there are many motels and inns along the boulevard, overnighters might find it enjoyable to walk through the downtown area. In this case, a beautifully landscaped raised median would entice pedestrians to walk along the boulevard and their crossing the boulevard would be more controlled and safer. It should be noted its sidewalks must be upgraded.

Another consideration would be a high percentage of the elderly in the city. As older people walk slower, a raised median would make it easier for them to cross the road if they desired. As of now, auto-oriented businesses thrive because pedestrian-friendly shops cannot. Raised medians may be the catalyst to help bring back pedestrians and shops.

Volume

Along most of the boulevard the ADT is around 40,000. This exceeds the recommended amount for a TWLTL. Raised medians are recommended by the FHWA, ITE, and CTR when ADT is above 24,000 – 28,000. According to volume, a raised median is recommended. The reason for this is because right angle accidents are not adequately prevented with a TWLTL. A raised median can restrict certain movements that will make right angle accidents in midblock sections less common. This is important because right angle accidents are associated with higher severity. Also, left-turns are controlled. With TWLTLs, motorists can make left-turns anywhere on the road. With a raised median, left-turns are restricted to intersections and midblock openings. Left-turn accidents account for almost three-fourths of all accidents (Figure A-4).

Another important factor with a high volume of traffic is the smooth flow of traffic. St. George Boulevard connects the interstate with Bluff Drive, which serves a very high ADT. When a raised median is present, the drivers have much less distractions of drivers making a left-turn from the TWLTL. There are also less opportunities for accidents because certain movements are restricted. Moreover, vehicle movements are more predictable, which enables motorists to feel safer behind the wheel. If the main purpose of St. George Boulevard is to move traffic east-west, a raised median will help that happen.

Delay

Delay is very difficult to measure, but the main causes of delay are easily recognized. Delay occurs most often when a road is blocked by vehicles that extend out into the through lanes from left-turn or right-turn lanes or traffic signals simply lower the capacity of the boulevard. A TWLTL is usually adequate when vehicles need to make left-turns because it removes the vehicle from the through lane. A left-turn bay built into a raised median is usually adequate as well. Judging by the types of businesses on the corridor, a large amount of left-turns will not be made except at Smith's Food and Drug at 400 West. The intersection at 400 West should be adequate for those turns. If a left-turn lane built into a raised median is not long enough to meet the demand it is difficult to change this without extensive reconstruction. For Saint George Boulevard, a TWLTL or a raised median would be adequate to keep delay low.

Driveways per Mile

Saint George Boulevard has 56 driveways per mile and 8 traffic signals per mile. According to previous studies, accidents per mile increase by 118% when there are 40 to 60 driveways per mile (Table A-11). This number 56 is close to 60. When there are 60 driveways per mile or more, then the increase is 174%. When driveways per mile increases, the margin between accident rate on TWLTLs versus raised medians increases. The accident rate on TWLTLs increases at a faster rate than raised medians. In fact, the accident rate actually decreases on raised medians when driveways exceed 60 per mile (Table A-13).

When signalized access points per mile are compared, raised medians have a lower accident rate compared to a TWLTL. When there are 6 or more signalized access points per mile, raised medians experience a lower accident rate than the raised median. This boulevard has 8 access points per mile. Hence, on this account, a raised median is an appropriate option.

Midblock Openings

Each segment is about 550 feet long. The length of 550 feet is not adequate to install midblock openings, according to Table A-15 of the guide. Therefore, midblock openings would not be permitted, as LT bays at intersections will occupy most of the distance. If left turns need to be made they would have to be done at the intersections. Since many of the businesses can be reached by making a left-turn from the TWLTL right now, adjustments in traffic behavior will have to be made. For instance, to get to a store on the opposite side of the street, a driver would either make a U-turn or take a left at the intersection and use Tabernacle Street or 200 North to swing back around and getting going in the right direction so a right turn can be made. This could be avoided if better site circulation were available so that motorists could navigate through store parking lots instead of using the adjacent roads. Also, Tabernacle St may have more traffic which may help the businesses on this street.

Number of Lanes

Saint George Boulevard has two lanes in each direction. This road however carries an ADT that adequately fills three lanes in each direction. It is highly recommended by the FHWA, CTRE and ITE to have a raised median when there are three lanes in each direction. Therefore, as far as the actual number of lanes is concerned a TWLTL is adequate for this road. However, since there is so much traffic on this road, a raised median may be recommended. The purpose behind having a raised median with three lanes is because the number of traffic movements increases dramatically with more lanes, not to mention with a TWLTL. A raised median is an appropriate option.

Evaluation of Result

Since most of the accidents that occur on St. George Boulevard are rear-end accidents, a raised median may not help decrease the major type of accident that currently takes place. However, a raised median will eliminate potential for midblock left-turn related accidents. A raised median might help improve pedestrian circulation on St. George Boulevard. Nothing was mentioned about beautifying the area, but a raised median could make the place look nice with trees and rocks and shrubs when combined with improvements to the sidewalks. The volume on the corridor seems to be the strongest point in favor of a raised median. Moving traffic through the area is important and a TWLTL may not be adequate or appropriate with the high traffic volume. A low amount of delay can be reasonably accommodated with either a raised median or TWLTL. There would be no midblock openings which would allow left-turns into businesses. With a raised median, motorists would have to always make right-turns into the businesses which may be a nuisance to some drivers. However, Tabernacle Street could serve as sort of a frontage road, if you will. Also, such movements would bring more traffic to this currently quite shopping street. The number of lanes on this corridor does not indicate a need for a raised median. However, the number of driveways per mile does indicate a need for a raised median. Raised medians are associated with fewer accidents per mile as the number of driveways or signalized access points increase above 40 driveways or 6 signals per mile. The boulevard has about 60 driveways and 8 signals per mile indicating a raised median is a legitimate option.

APPENDIX B: MANAGER SURVEY

Appendix B presents a copy of the manager survey used for this opinion survey.

Store Name:____________________
Filled in by:____________________

Brigham Young University
Provo, UT 84602

Economic Impact of Median Design along University Parkway
(Business Impact Survey)

Orem, UT
Purpose of Survey

The Utah Department of Transportation is studying the effect of raised medians. Guidelines are being developed for the installation of raised medians, and as part of this project, economic impact to adjacent businesses is being studied. This is an anonymous survey conducted by BYU students to determine store managers' opinions regarding how raised medians have affected business. Completing this survey is voluntary. Please answer each question honestly. <u>All answers will be held confidential.</u>

Thank you for filling out this important survey!!

1. When did this business begin operations at this location?

   Month Year
   _____ ____

2. What do you believe is the percentage of your customers who are passerby customers and those who intend on stopping at your business? Passerby customers are those customers who are not intending to stop at your particular business (i.e., impulse customers) as opposed to planned stops by customers who had intended on stopping at your business.

   Percent passerby traffic___ Percent planned stop___

3. Do you believe your regular customers have remained about the same, are more likely, or have been less likely to visit your business due to the raised median?

   Less likely___ Stay about the same___ More likely___

4. Please rank the following considerations from "1" to "6" (with "1" being the most important) that consumers use when selecting a business of your type:

Distance To travel	Hours of Operation	Customer Service	Product Quality	Product Price	Accessibility to Store
—	—	—	—	—	—

5. Please indicate below whether you feel the installation of the raised median has made the following items "Better," "Worse," or about "The Same" as before the median was installed.

	Better	Worse	The Same
Traffic Congestion	____	____	____
Traffic Safety	____	____	____
Property Access	____	____	____
Business Opportunities	____	____	____
Customer Satisfaction	____	____	____
Delivery Convenience	____	____	____

6. How many people are employed by your business? Please give the average annual number, including working owner and/or manager to the best of your knowledge. Construction year is shown in bold.

	1997	1998	1999	2000	2001	**2002**	2003
Full-time	____	____	____	____	____	____	____
Part-time	____	____	____	____	____	____	____

For questions 7-9,

- Please give your best estimate of the percentage impact, up or down, on your business.
- If you do not think there was a large change during construction or if there has not been a large change after the installation, then mark an "X" for "No change."
- Please place an "X" for "Not sure" if you are uncertain about what the effect was during the construction or is now after the installation.
- Please take into consideration the current economic slump.

During and after the construction, has there been a change in:

7. Your number of customers per day?

	During Construction (As compared to before construction)	After Installation (As compared to before construction)
Percent increase	____%	____%
No change	____	____
Percent decrease	____%	____%
Not sure	____	____

8. Your number of full-time employees?

	During Construction (As compared to before construction)	After Installation (As compared to before construction)
Percent increase	____%	____%
No change	____	____
Percent decrease	____%	____%
Not sure	____	____

9. Your number of part-time employees (enter as equivalent full-time employees)?

	During Construction (As compared to before construction)	After Installation (As compared to before construction)
Percent increase	____%	____%
No change	____	____
Percent decrease	____%	____%
Not sure	____	____

Please use this space to discuss any additional thoughts you may have about the raised median installation along University Parkway. Please attach an additional page if necessary.

Once again, thank you very much for your time in completing this important survey! If you have questions regarding this survey or the study please contact the research supervisor Dr. Mitsuru (Mike) Saito at (801) 422-6326. If you have questions regarding your rights as a participant in research projects, you may contact Dr. Shane S. Schulthies, Chair of the Institutional Review Board for Human Subjects, 120B RB, Brigham Young University, Prov, UT 84602; phone, (801) 422-5490.

APPENDIX C: CUSTOMER SURVEY

Appendix C: presents a copy of the customer survey used for this opinion surveys.

Store Name:___________________________

Brigham Young University is studying the economic impact of the raised median installation along University Parkway in Orem, Utah from 400 W to 200 E for the Utah Department of Transportation. This is an anonymous survey to evaluate how customer's opinions are affected by the recently built raised median. There are 11 questions that take 2-3 minutes to answer. Completing this survey is voluntary. Please answer each question honestly.

1. Are you aware of the project in which a raised median was installed along University Parkway from 400 W to 200E?
   ___Yes ___No

2. Did you patronize this business prior to the construction of the raised median?
   ___Yes ___No

3. When leaving this business will you have to go the opposite way than you would like and make a U-turn (or series of right turns)? If answer is No, skip to 5.
   ___Yes ___No

4. Is this driving maneuver different than before the raised median was installed along the center of University Parkway in front of this business?
   ___Yes ___No

5. If the construction of the raised median prevents you from making a left-turn from the two-way left-turn median lane, do you believe you will be more likely to visit this business, less likely, or about the same?
   ___Less likely ___Stayed about the same ___More likely

6. Did you make a special trip to visit this business or just stop here because it is convenient on the way to your primary destination?
   ___Special trip just to this business (or went out of way to stop here)
   ___Pass-by / convenient

7. If you visited this business prior to the median installation, do you believe you are now more likely or less likely to visit this business or is it about the same?
   ___Less likely ___Stayed about the same ___More likely

8. If less likely in Question 7, why?
   ___Access more difficult
   ___Takes longer to get here
   ___Other stores more convenient
   ___Other, please describe________________

9. If more likely in Question 7, why?
   ___Access more convenient
   ___Less time to get here
   ___Access more safe
   ___Other, please describe________________

10. Please rank the following considerations from "1" to "6" (with "1" being the most important) that you use when selecting a business of this type:

Distance To travel	Hours of Operation	Customer Service	Product Quality	Product Price	Accessibility to Store
___	___	___	___	___	___

11. Please indicate below whether you feel the installation of the raised median has made the following items "better," "worse," or about "the same" as before the median was installed.

	Better	Worse	The Same
Traffic Congestion	____	____	____
Traffic Safety	____	____	____
Property Access	____	____	____
Customer Satisfaction	____	____	____

Do you have any other comments regarding the raised median (Please write them here)?

If you have any questions regarding this survey or the study please contact the research supervisor Dr. Mitsuru (Mike) Saito at (801) 422-6326. If you have questions regarding your rights as a participant in research projects, you may contact Dr. Shane S. Schulthies, Chair of the Institutional Review Board for Human Subjects, 120B RB, Brigham young University, Provo, UT 84602; phone, (801) 422-5490. Thank you very much for your time in filling out this survey!

APPENDIX D: CUSTOMER AND MANAGER SURVEY COMMENTS

D.1 Customer Survey Comments

1 It looks nice but the money could have gone elsewhere
3 I would have felt better if they had planned and done it right the first time instead of realizing they needed to make adjustments after the first phase. Big time waste of tax payers dollars
8 I've seen some people get really confused about entering the freeway south bound since this change was finished
10 It looks good, better than before and somehow makes the traffic a bit safer.
15 It is nice looking but does make it harder to get to places. It is frustrating if I miss my turn and have to drive out of my way to turn.
17 It can be fairly ANNOYING! When people don't know it is there – they drive dangerously trying to figure out where to turn in.
18 I don't like it. It makes left turns on this road terrible (both turning left onto the Parkway and from the Parkway to stores
23 Good job guys.
36 Hates the raised median
45 More dangerous
46 Infinitely better – saves lives
49 Traffic is a nightmare all up and down this street. I usually try to avoid taking this street. I usually go on 1200 S or other supporting streets because this one does not make for easy access.
51 I drive through parking lot to a light instead of left on Parkway
57 Plants make it look nice. Outside should look good – Appealing
59 Lack of customer service here
60 Doesn't come here often
61 Doesn't matter
63 All for raised medians because reduces crashes. People would dart across road without them.
65 Doesn't like it.
75 It would be more convenient to be able to turn into the [store] parking lot without the hassle of the raised median. I realize that it helps with U turns but really the congestion would be less if it was not there
76 Wishes they had a median opening for this business. She has to drive through another store's lot.
77 Grateful it was installed because of fatal crash. It's too bad it wasn't installed earlier.
85 Can't say much because he builds the medians
87 Kind of annoying to them
88 Should have raised medians on all busy streets. They save lives.
89 Frustrated that you have to go clear to the median opening to get around. Should be median openings. Doesn't like raised median that is in front of her business.
100 If maintained with landscape then good

102 Upset that Granite is moving. Better customer service than RC Willey. Raised medians are annoying.
103 Medians suck
106 Medians look nice if planted
107 I like them
110 Only if safety is improved
111 Ok here but bad at Wal-Mart
112 Looks nice
116 I like the trees
117 Likes green things
125 I don't like them
130 Don't put them around me
131 Inconvenient
132 Likes it, pretty, adds to community
136 If I can drive on them, I will
142 Driving maneuver: They come straight across from south of University, so they go straight at RC Willey at the light and cut through parking lot-it's just easier
143 Looks nice
149 Forces too many u-turns
151 It's pretty, but makes things difficult
154 Likes it very much because it is beautiful. Road is supposed to be a parkway by the name anyways
161 If rush hour, they are deterred from coming to store
162 Looks nice. They might be a pain, but they make the city look a lot nicer.
164 They kind of suck
165 Less chance of head-on collisions
166 Didn't affect me that much
167 More difficult when congested
168 Kind of a pain. Don't like traffic. Ask us about roundabouts, we'll fill out a survey on those.
169 Makes it difficult. I don't like them. Bad idea.
173 Feels safer because she knows the people who were killed in the car crash [on University Parkway a few years ago], which was caused by a head-on collision.

D.2 Manager Survey Comments

2 We are an Insurance Claims Office. Our Business is not generated by passerby or planned. This survey would be more appropriate if it was an agent sales office.
3 At the holiday we have 50 to 60 employees
4 They need to put a(n) [turn] arrow [at 400 W] to cut down on people taking chances when crossing the street. The amount of car crashes has not decreased.
5 Not able to determine question 8 or 9. He has had continuous growth. My business is probably not impacted as much by the installation because of its nature. However, other businesses in the building may feel the impact. I feel that there is some impact in trying to rent the building to tenant businesses.

6 Our business does not rely on drive by business. The best improvement has been the stop light which makes it much safer to turn into our business, it would be better not to have trees in the median for vision reasons.

7 Raised median has had little or no effect. The planting of trees on the other hand has had more negative effect.

9 We have seen some growth in our business since construction but our growth has been less than our competition in Honda. We are seeing fewer customers but our sales have increased because of our increase in trained employees not because of increase in traffic. Access to our property is very difficult!

10 Doubtful that median has had any effect.